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WASTE AUTOMOTIVE LUBRICATING OIL REUSE AS A FUEL

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Approximately 2.2 billion gallons of new lubricating oils were sold in the United States during 1972. While figures vary widely on the subject, it is estimated that 50 percent of these oils are consumed in their various uses. The remaining 1.0 to 1.3 billion gallons of waste oil are potentially available for recycling and reuse. Of this amount, it is estimated that approximately 400 to 600 million gallons are disposed of into the environment each year in the United States. One alternative which has been discussed, but not adequately researched, as a means of beneficially disposing of the waste oil is to use it as a blended fuel oil. Given the current energy crisis, and environmental policies, this disposal alternative has become increasingly more important. This report examines the potential marketability of waste oil fuels and the characterization of untreated waste oil. The report then analyzes the technical, environmental, and economic feasibility of using untreated and treated waste oil as a blended fuel oil. The report contains a bibliography.

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REUSE AS A FUEL

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ABSTRACT

This study evaluates the technical, economic and environmental feasibility of automotive waste oil reuse as a fuel. The supply and potential marketability of waste oil fuel is considered in relationship to existing and projected fossil fuel usage in the United States. Although the total automotive waste oil generated annually represents less than 0.5% of the total U. S. fossil fuel production, it is concluded that waste oil can serve as an economically advantageous supplement to present domestic fuel supplies. Moreover, its use will alleviate a serious waste oil disposal problem.

The physical and chemical properties of waste oil are presented and serve as the basis for subsequent assessment of waste oil usage options. Options considered are the use of untreated waste oil as a blended fuel oil or as a supplement to coal combustion and the use of waste oil following treatment to alleviate technical and environmental impacts. Although the use of untreated waste oil blends appears feasible for large utility and industrial boilers, some treatment will be required for smaller boilers. Various treatment methods are discussed and their cost and effectiveness assessed. The reduction of environmental impacts by the use of particulate emission control systems also is considered in relationship to the cost and effectiveness of control equipment, and present utility and industrial utilization of fuel and control equipment.

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SECTION I

CONCLUSIONS

1. Potential Waste Oil Marketability

- Supply and Production

  a. If all automotive waste oil generated annually were available for fuel reuse, this total fuel energy would represent less than 0.5 percent of the total annual coal and crude oil energy production in the United States. Waste oil fuels, therefore, may serve as incremental regional supply inputs to supplement existing domestic fuel supplies.

  b. Waste oil generation is a variable process, varying both spatially and temporily, thereby affecting the regularity of supply availability for fuel usage. Use may be restricted to a reserve or supplemental fuel in the short term, while in the longer term, systems may be developed to promote supply regularity through improved collection, storage and/or pretreatment, and distribution systems.

  c. A range of alternate blended and unblended waste oil fuel products may be marketed based on the extent of untreated oil reprocessing and the nature of fuel combustion. Associated with this range of waste oil fuel products is a range of market prices, with differences reflecting the degree of reprocessing and handling.

  d. Comparative fuel costs for coal, virgin fuel oils, and untreated waste oil show a large competitive advantage for waste oil in present fuel markets. Average prices for untreated waste oil in December 1973 were about 30 percent of average distillate fuel oil prices and 40 percent of residual oil prices. This fuel price advantage leaves a large cost margin for pretreatment to meet technical and environmental quality specifications.

- Demand and Consumption

  a. Rapidly expanding national fuel energy consumption, combined with an unstable foreign petroleum supply market, have created a domestic fuel market supply-demand imbalance. This imbalance requires expanded domestic energy production, energy conservation, and development of new fuel supply forms and sources. Reuse of waste oil as fuel promotes energy conservation and provides a supplemental fuel supply source to help meet demand.

b. The electrical power industry, which accounts for about 25 percent of the nation's total annual fossil fuel consumption, represents a large potential demand market for waste oil fuels in most regions of the nation. Some electric power plants are currently combusting waste oil routinely or are testing waste oil fuels for potential routine usage; and 86.5 percent or 59 of 68 electric utility companies responding to a nationwide survey felt that some form of a waste oil fuel product could be used at their facilities.

c. The industrial sector of the economy, presently the largest consumer of energy in the United States using about 30 percent of the nation's annual energy input, contains numerous process applications to which waste oil fuels may be applied. Several industrial plant operating factors may serve as criteria in identifying potential users of waste oil fuels to include:

   - Present fuel energy consumption levels
   - Installed particulate matter emission control technology employed
   - Present trends in waste oil fuel use and/or combustion testing.

   Based on these factors, selected firms in the following Department of Commerce industrial categories represent prime potential consumers: (1) lumber and wood products, (2) paper and allied products, (3) chemical and plastic products, (4) petroleum and coal products, (5) rubber and plastic products, (6) stone, clay, and glass products, and (7) primary metal industries. In general, industrial firms are more heterogeneous in character than electric power plants, and require more detailed analysis of fuel logistical and utilization methods before potential regional waste oil users may be identified.

- Institutional and Legal Factors

The ultimate sale and use of waste oil fuels may be affected by a range of non-market, institutional factors based on the specific locality and application being investigated. These may be divided into several categories to include:

a. Laws and regulations uniquely applicable to waste oil

Presently limited, but generally favorable toward waste oil fuel usage by restricting the marketability of waste oil derived products relative to virgin oil derived products thereby restricting the range of economically viable waste oil reuse options.

b. Environmental management and pollution control actions directly affecting the use of waste oil fuel

Existing or anticipated air quality and emission standards directly govern the acceptable quality of waste oil fuel at the federal, state, and/or local levels. These include particulate matter standards and hazardous pollutant standards for lead and other metallic and inorganic pollutants found in waste oil.

c. Environmental control actions indirectly influencing waste oil fuel use

These actions generally tend to enhance its marketability potential. First, air pollution emission controls have resulted in the installation of stack gas effluent controls which may remove harmful particle emissions from waste oil combustion without a large additional outlay of capital for control hardware. Second, sulfur oxide emission controls and fuel sulfur content regulations tend to improve the market demand for recovered waste oils low in sulfur for use as blended fuels.

2. Technical Impacts of Untreated Waste Oil Combustion

Because of the level and variability of contaminants in untreated waste oils, the following technical problems have been encountered as a result of untreated waste oil combustion:

- Stratification in storing with distillate oils because of differences in specific gravity

- Fuel line freezing, burner flameout, and inconsistent heating values due to excessive water content

- Burner and pump abrasion; line strainer plugging and storage tank sludge buildup due to excessive coarse solids content

- Contribution to scaling and corrosion of heat transfer surfaces in boilers due to high ash content

- Contaminants in waste oil influencing product composition when direct-fired into kilns, driers, and other process equipment

3. Environmental Impacts of Untreated Waste Oil Combustion

Although untreated waste oil contains significant levels of metal contaminants (i.e., up to 1 percent by weight lead), its utilization for selected applications has been shown to result in maximum ground level concentrations of lead at least an order of magnitude below a recently proposed 90-day average standard of 2 micrograms per cubic meter (2 $\mu g/m^3$). Such applications include:

Application	Fuel	Total firing rate (gal/hr)	Weight percentage of waste oil
500 mw Utility Boiler	Blend of residual and untreated waste oil	31,000	5.0
56 mw Utility Boiler operating at 20 mw	Blend of residual and untreated waste oil	1,900	7.4
Industrial Steam Boiler	Blend of residual and untreated waste oil	476	75.0
Industrial Steam Boiler	Untreated waste oil	100	100.0
Auxiliary fuel for municipal incinerators	Untreated waste oil	300	100.0

The resulting ground-level lead concentration for a specific application depends on such factors as stack height; flue gas velocity and temperature; and meteorological and topographical conditions. GCA feels, however, that the conditions upon which ground-level concentrations were estimated for the above applications were not atypical and therefore represent a realistic order of magnitude estimate for similar and related applications.

4. Impact Reduction Alternatives - Pretreatment

Technical and environmental impacts can be alleviated by employing various levels of existing technology to pretreat waste oil prior to combustion. These pretreatment techniques include:

- Vacuum Distillation or Solvent Extraction

  These are high level, commercially available pretreatment processes which essentially remove all contaminants and therefore eliminate the adverse technical and environmental impacts resulting from waste oil combustion. These high level pretreatments, particularly vacuum distillation, yield large quantities of waste residues which must be disposed of in landfills or by further processing.

- Settling and/or Centrifugation

  These are lower level pretreatment operations which are capable of removing coarse solids and free water (water which is neither emulsified or chemically bound). These techniques can be combined with heating and demulsification to further enhance coarse solids removal and to remove all volatiles and remaining water.

These lower level pretreatment options will alleviate the technical problems mentioned above which are associated with the storage, transport and burning of waste oil. However, these pretreatment systems will not significantly reduce the soluble and submicron sized ash constituents in the waste oil. These remaining contaminants contribute to scaling of heat transfer surfaces as well as contain virtually all the trace metals which are of concern from an environmental viewpoint.

5. Impact Reduction Alternatives - Emission Control Systems

High efficiency particulate control devices can reduce lead and other submicron-sized emissions and therefore their resulting contributions to ambient concentrations by one to two orders of magnitude (i.e., 90 to 99 percent control). Fabric filter baghouses, electrostatic precipitators and to a lesser degree high energy venturi scrubbers, are all capable of achieving this range of performance. It should be emphasized, however, that optimal performance of a control system can only be achieved if the system is designed for the primary fuel type and operating characteristics employed. For example, optimal performance of an electrostatic precipitation system at Northern States Power Company, has been observed in removing 98+ percent of the lead generated from the firing of a 3 wt. percent waste oil/ 97 wt. percent coal fuel blend. This system was designed for a coal-fired plant. However, such performance could not be achieved if the plant were to convert over to residual oil as its primary fuel.

6. Capital Investment and Operating Costs for Impact Reduction Alternatives

The capital investment and operating costs associated with waste oil pretreatment options and emission control systems are summarized below. These pretreatment costs are based on a pretreatment plant capacity of 15,000,000 gallons per year (85 percent yield or 12,750,000 gallons per year output for settling, centrifugation, and solvent extraction; 70 percent yield or 10,500,000 gallons per year for vacuum distillation). The costs associated with the emission control systems are based upon a stack flow of one million actual cubic feet per minute (acfm). This is the approximate stack flow of a large utility boiler (~ 500 mW) utilizing 12,750,000 gallons per year of waste oil to supply 5 percent of its energy requirements; a reasonable example of a large-scale application for waste oil fuel utilization. The benefits derived from the alternatives presented below are delineated in Item 5 above.

	Capital investment	Annual operating cost	
Impact Reduction Options	Millions of $'s	Millions of $'s	¢/gal of waste oil
Pretreatment Options:			
Low Level			
Settling	1.4	1.4	11
Centrifugation	1.4	1.3	10
High Level			
Vacuum Distillation	1.8	1.3	12
Solvent Extraction	1.8	1.6	12
Emission Control Options:			
Precipitators	3.1	0.3	2
Fabric Filtration	2.9	1.1	9
High Energy Scrubbers	2.5	1.4	11

Capital and operating costs for different capacities can be obtained from Figures presented in Section IX.

7. Comparison of Waste Oil Selling Price with Alternative Virgin Fuels

Waste oils undergoing a high level of pretreatment (vacuum distillation or solvent extraction) are very competitive relative to virgin fuel oils but less competitive relative to coal. Based on a capacity of 15,000,000 gallons per year for the treatment facilities considered a cost of untreated waste oil to these facilities of 50 cents per gallon, the comparative selling prices for waste oil and virgin fuels are presented below for the Northeast:

Fuel Type	Cost (cents/million BTU's)
Waste oil with low level of treatment	138.8
Waste oil with high level of treatment	153.3
Residual oil (< 0.5%S; Dec. 73)	140.3
Residual oil (0.5-1.0%S; Dec. 73)	125.0
Distillate oil (Dec. 73)	191.6
Coal (> 3%S; Sept. 72)	39.2
Coal (1-3%S; Sept. 72)	43.6
Coal (< 1%S; Sept. 72)	46.0

8. Favored Use Options

The purpose of treating waste oil is to reduce environmental damage and technical impacts while at the same time adding to energy sources. Certain alternatives represent a path of least resistance in the achievement of these two goals.

(1) Large users, especially utilities, could blend small percentages of a low-treated or untreated waste oil with their existing energy source without necessarily adding emission control equipment.

(2) Medium-sized users with existing effective emission control equipment could blend higher amounts of high-treated or low-treated waste oil with their other fuel sources.

(3) High-treated waste oil combusted by itself by a number of relatively small users.

SECTION II

RECOMMENDATIONS

1. Although this study addresses itself to the technical, environmental and economic factors affecting waste oil as a fuel, its scope does not include techniques for systematically weighting the importance of these parameters at a regional level. The ability to do so would provide invaluable insight into the selections of optimal regional market size, treatment location, and treatment options. Consequently, it is recommended that future studies include the development of a comprehensive regional model(s) to specify optimal regional market size, treatment location(s), and treatment option(s). This model will utilize the following key input parameters.

Supply and Production Factors:

- Untreated waste oil recovery and collection

    a. Number of sites
    b. Collection system

- Storage - Reprocessing

    a. Process alternatives - regional constraints
    b. Technical limits to size
    c. Economic constraints
    d. Input requirements

- Product Marketability

    a. Availability of substitute fuels
    b. Market supply price - private market and/or public subsidization
    c. Other waste oil fuel products and their marketability

- Regulations - Institutional Constraints

Demand and Consumption Factors:

- Types of Potential Users (Cross-section)
    - a. Electric utilities
    - b. Industrial firms
- Number of Potential Users
    - a. Size
    - b. Geographic distribution
- User Costs Components
    - a. Waste oil fuel supply price
    - b. Cost of fuel use
        - (1) maintenance and operation
        - (2) occupational health impacts
        - (3) emission control utilization including collected flyash byproduct quality impacts and resultant salability
- Regulations - Institutional Constraints

2. This study indicates that several estimates of maximum lead ground-level concentrations have been made for a variety of waste oil fuel combustion applications. These estimates have utilized standard diffusion modeling techniques as well as plant operating and meteorological data. The estimates show that for typical plant meteorological and topographical conditions, ground-level concentrations are below a recently proposed standard of 2 micrograms per cubic meter. Although these results are consistent with the results found experimentally and reported in Section I-3, it is recommended that a comprehensive air quality sampling program be executed in the near future in conjunction with a utility company or industry currently burning or planning to burn waste oil. The purpose of this sampling program is to validate models such as the ones utilized in this study to develop lead ground-level concentrations.

3. In conjunction with an air quality monitoring program such as discussed above, it is recommended that more substantial data be generated on incremental operating and maintenance costs associated with waste oil utilization. For example, incremental costs associated with the following operations at a utility boiler should be evaluated:

- Sootblowing
- Boiler cleaning, including potential occupational health hazards associated with the cleaning procedure
- Fuel storage and handling
- Burner maintenance
- Emission control operation and maintenance
- Salability of byproduct flyash from particulate control system

Such costs would provide much needed inputs into the iterative process of formulating the overall economics of waste oil fuel utilization.

4. Additional laboratory and pilot scale work is needed to evaluate the effectiveness of waste oil pretreatment and control options. This additional effort should focus on the following areas:

- Evaluation of the effectiveness of chemical treatments such as demulsifiers and flocculants on solids removal.
- The effectiveness of various solvents should be evaluated in regard to separation of waste oil from its impurities. Consideration should also be given to solvent-oil separation methods other than distillation, such as crystallization, and differential solubilities as a function of temperature.
- The further characterization of the physical and chemical state of additives and contaminants. This would help in evaluating the effectiveness of the various pretreatment options available.

SECTION III

INTRODUCTION

This report addresses two problems of increasing concern in urban areas throughout the country:

- The recovery and utilization of growing quantities of waste automotive lubricating oils, economically and without contributing to environmental insult.

- The increasing gap between the demand for fuel and the available supply to meet this demand.

This study investigates the feasibility of alleviating these two problems by utilizing the waste lubricating oil as a fuel in power plant and industrial applications. Specifically, this study examines the economic, technical, and environmental factors associated with the use of waste oil as an industrial fuel source.

BACKGROUND

Two broad categories of waste oil include residue oil derived from automotive and industrial lubricating oils. This report focuses on the reuse of waste oil derived from automotive and other vehicular lubricating oils.

It is currently estimated that as much as 700,000,000 gallons of waste automotive lubricating oils are generated annually in the United States. These waste vehicular lubricants are a heterogeneous grouping of oils including:

- Crankcase oils, transmission fluid, hydraulic oil, and differential gear lubricants which are derived from service stations and garages; automobile dealers and fleet operators; agricultural and marine applications; and individual vehicle operators.

Currently, a range of waste oil reuse and disposal techniques are being utilized or are being investigated for potential application.[1] These include:

- Re-refining
- Incineration
- Land application and disposal
- Deep well disposal
- Combustion as a fuel

Re-refining, once the primary use for collected oils, has become less attractive due to such technical, economic, and institutional factors as: more rigid specification requirements for automotive lubricants; increasing costs associated with re-refining to remove spent additives and impurities and to bring oils back up to specifications; disadvantageous tax situations in many localities as compared with virgin fuels; and labeling requirements in many localities to indicate that the oil was "previously used."

Incineration of waste oil has not been widely advocated because a "valuable" commodity is being discarded as opposed to recycled. There are, however, specific instances when the incineration of waste oil is beneficial such as when utilized in a municipal incinerator to improve the combustion process.[3] Land application and deep-well disposal also result in the discarding of a potentially valuable resource as well as posing, in the case of ground-level disposal, a serious pollution threat to water tables and estuaries.

The inherent limitations of the first four reuse and disposal schemes listed above, in addition to inadequate industrial virgin fuel supplies, have resulted in increased utilization of and attention to waste oil as a fuel. Waste vehicular oil contains approximately the same heating value as virgin oil (15,000 to 20,000 BTU/lb)[2,3,4] and burning this oil as a fuel component implies economic and efficient resource utilization as well as the mitigation of potential oil pollution environmental impacts. The relative potential merits of waste oil reuse as a fuel, which are the primary motivation factors for the conduct of this study, include:

- Provides a fossil fuel source to supplement growing energy demands
- Provides a waste oil reuse method with broad applicability in most regions of the nation
- Achieves a reuse mechanism yielding minimal unusable byproducts for subsequent disposal
- Achieves a reuse procedure requiring no or minimal new technology development or large capital equipment outlays for combustion and ultimate disposal

Significant uncertainty, however, exists concerning the use of waste oil derived fuels in terms of combustion equipment operation and maintenance impacts, and air pollution emissions from this heterogeneous mixture of oils. These technical and environmental factors associated with waste oil fuel combustion then become critical parameters in the economic assessment of alternate waste oil fuel combustion trade-offs.

PURPOSE AND SCOPE

The purpose of this study is to evaluate the technical and environmental feasibility and economic factors associated with utilizing waste vehicular lubricants as an industrial fuel. Emphasis is placed on use of waste oil as a blended fuel in steam-generating power plants, in industries currently burning waste oil, and in industries whose energy needs and level of particulate emission control make waste oil utilization potentially attractive.

The study includes the determination of:

- Potential marketability of waste oil Fuels (Section IV)

  A review of the current and future industrial fuel demand for waste oil is presented together with current and projected waste oil supplies. Price and geographic variations in supply and demand are two parameters evaluated in detail. The identification and implication of regulations influencing the use of waste oil as a fuel will also be presented. This section lays the foundation for the potential roles that waste oil can play as an industrial fuel source.

- Characterization of untreated waste oil (Section V)

  The important characteristics and properties of waste oil and the primary virgin fuels are presented and compared. The information generated in this section will be utilized as primary inputs in the determination of the technical feasibility (Section VI) and environmental impacts (Section VII of untreated waste oil as an industrial fuel.

- Technical feasibility of untreated waste oil as a fuel (Section VI)

  The technical advantages and disadvantages of utilizing untreated waste oil as an industrial fuel is presented. A key parameter evaluated in this section is the influence of blending ratios (ratio of waste oil to virgin fuel) to the technical viability of waste oil as a fuel.

- Environmental impacts of untreated waste oil as a fuel (Section VII)

  The impact to the environment of untreated waste oil as an industrial fuel is examined. The major emphasis is placed on the estimation of lead emitted to the atmosphere and resulting contribution to maximum ground-level lead concentrations.

- Reduction of waste oil fuel combustion impacts (Section VIII).

  This section presents viable technical options for alleviating the adverse technical and environmental impacts (presented in Sections VI and VII) of waste oil utilized as an industrial fuel.

- Economics of impact reduction alternatives (Section IX)

  The economics of the impact reduction alternatives discussed in Section VIII are presented here. Capital investment and operating costs are provided for varying plant and equipment capacities.

- Market analysis of waste oil fuels (Section X)

  The array of costs associated with waste oil utilization as a fuel are developed and compared with existing alternative virgin fuels.

Each of these areas will be discussed in detail in the remaining sections of this report.

SECTION IV

POTENTIAL MARKETABILITY OF WASTE OIL FUELS

The scope of this study has been structured to evaluate the technical and economic feasibility of waste oil reuse as a fuel, and economic factors associated with attaining acceptable waste oil fuels. This economic evaluation provides cost estimates for attaining acceptable quality waste oil fuels but is only a partial measure of the benefits to be derived from its usage; namely, the explicit energy value derived from its combustion, and its potential market price as a fuel. These cost and market values (prices) provide the essential data for private market feasibility assessment of establishing a separate waste oil fuel supply firm or making investments at the user level for internal fuel supply for combustion. For a total benefit-cost feasibility appraisal, however, the abatement of potential oil pollution impacts must be assessed. The aggregating of these implicit benefits with the fuel energy asset value must be undertaken in order to make public investment/policy decisions concerning waste oil fuel systems: public subsidization of private systems; public provision of collection, pretreatment and/or distribution; policies regulating private marketing, etc.

A pragmatic assessment of waste oil reuse as a fuel must begin with an evaluation of the potential marketability of waste oil fuels; i.e., potential supply/production, demand/consumption, and institutional/legal factors influencing this market analysis.

POTENTIAL SUPPLY OF WASTE OIL FUEL

Magnitude and Distribution of Supply

The magnitude and distribution of vehicle waste oils generated in the United States are important parameters governing the potential supply of waste oil fuel products. National, regional, and state estimates of waste oil lubricants have been derived based on the annual use of virgin oil used for industrial and vehicle lubrication,[5] and a detailed analysis of the approximate percentage of this oil not consumed in the original application.[6] National and regional waste oil supply projections are presented in Table 1. A more detailed statewide tabulation appears in Appendix A of this report. In general, focusing on vehicle lubricants, such as automotive crankcase drains, the amount and distribution of this waste oil will correspond with population and vehicle use densities: highly populated metropolitan regions will exhibit a

Table 1. NATIONAL WASTE OIL SUPPLY PROJECTIONS BY U.S. CENSUS REGIONS 1971[a]

Census Region	Estimated waste oil supply[b]	
	Vehicle (gal)	Industrial (gal)
New England	28,410,650	11,823,629
Middle Atlantic	85,817,580	61,829,173
South Atlantic	77,125,940	31,751,940
East South Central	48,109,500	18,508,285
East North Central	146,363,970	93,815,889
West North Central	77,013,540	14,985,071
West South Central	82,689,610	52,183,669
Mountain	36,569,250	7,435,345
Pacific	98,355,350	26,035,678
U.S. Total	680,455,390	318,368,679

[a] Data and reference sources:

1. Environmental Quality Systems, Inc., Waste Oil Recovery Practices, State of the Art (1972), prepared for the Maryland Environmental Service and U.S. Environmental Protection Agency, December 1972.

2. U.S. Department of Commerce, Bureau of the Census, U.S. Census of Population 1970, Vol. I, Washington, D.C.: U.S. Government Printing Office, 1972.

3. Arthur D. Little, Inc., Study of Waste Oil Disposal Practices in Massachusetts, report to the Commonwealth of Massachusetts, Division of Water Pollution Control, January 1969.

[b] Estimating procedure

$$\left[\begin{array}{c}\text{Estimated}\\ \text{Vehicle}\\ \text{Waste Oil}\\ \text{Supply}\end{array}\right] = \left(\begin{array}{c}\text{Annual Per Capita}\\ \text{Automotive}\\ \text{Oil Consumption}\\ \text{by State 1971}^{1}\end{array}\right) \times \left(\begin{array}{c}\text{1970 State}\\ \text{Population}^{2}\end{array}\right) \times \left(\begin{array}{c}\text{66\% = Estimated}\\ \text{Portion of Virgin}\\ \text{Oil Available As}\\ \text{Waste}^{3}\end{array}\right)$$

$$\left[\begin{array}{c}\text{Estimated}\\ \text{Industrial}\\ \text{Waste Oil}\\ \text{Supply}\end{array}\right] = \left(\begin{array}{c}\text{Annual Per Capita}\\ \text{Industrial}\\ \text{Oil Consumption}\\ \text{by State 1971}^{1}\end{array}\right) \times \left(\begin{array}{c}\text{1970 State}\\ \text{Population}^{2}\end{array}\right) \times \left(\begin{array}{c}\text{30\% = Estimated}\\ \text{Portion of Virgin}\\ \text{Oil Available As}\\ \text{Waste}^{3}\end{array}\right)$$

higher waste oil supply potential due to the concentration of motor vehicles, and thus lubricating oil use.

Industrial lubricants, as shown in Table 1, constitute about 32 percent of the total estimated waste oil supply. Industrial lubricant utilization and disposal practices are more complex than for automotive waste oils. Because of their wide variation in properties, they are not generally reprocessed to fuel. Certain oils, such as hydraulic oils, even are compounded with ignition inhibitors to insure safety in their normal application.[3] For these reasons, this study will concentrate on waste automotive oils, and industrial lubricants will not be considered further.

A convenient index of the relative magnitude, 680 million gallons of waste vehicle lubricants generated annually, may be derived through comparison with recent fossil fuel production and consumption trends in the United States. Table 2 provides a regional and national accounting of domestic coal and petroleum production and corresponding consumption levels in 1971.[7] Based on potential heat energy from fuel combustion, the potential waste oil supply represents less than 0.5 percent of the total coal and crude oil annual production, as illustrated in Table 3. Assuming that all vehicle waste oil generated annually in the United States were available for fuel use, Table 3 further shows that this would only constitute about 1 percent of the total coal and 5 percent of the total oil supply consumed by steam-electric power plants in 1970. In overview, waste lubricating oil does not represent a large new alternate source of fuel energy; rather waste oil fuel may serve as an incremental supply input to supplement existing domestic fossil fuel supplies. As a fuel supply supplement, local and regional factors associated with waste oil generation, collection, and related market forces will dominate waste oil fuel production decisions. This regional supply orientation implies a close balance of production and consumption levels by region, unlike the pattern of crude oil production and petroleum products consumption imbalance exhibited in Table 2, arising from inter-regional marketing and foreign importation of fuel.

Supply Regularity, Quality, and Alternate Fuel Products

In addition to potential supply magnitude and distribution dimensions, other waste oil fuel supply characteristics may serve as ancillary criteria in marketability evaluation. Principal supply factors for consideration include: regularity of supply, quality of supply, and alternate forms of waste fuel oil products. Waste oil generation for potential fuel reuse is a variable process over time, resulting in an irregular pattern of waste oil supply availability. This irregular availability characteristic, varying both spatially and temporily, greatly reduces the reliability of potential fuel supply at the present time. Use may be restricted to a reserve or supplemental fuel supply in the short term, while in the longer term systems may be developed to promote supply regularity through improved collection, pretreatment and/or storage, and distribution systems.

Table 2. PRODUCTION AND CONSUMPTION OF FOSSIL COAL AND OIL FUELS IN THE UNITED STATES: MAGNITUDE AND REGIONAL CHARACTER 1971[a]

Region	Coal: anthracite, bituminous, and lignite		Crude oil: petroleum products	
	Production (million tons)	Consumption (million tons)	Production (million gal)	Consumption (million gal)
New England	0	2.5	0	16,939.4
Middle Atlantic	81.5	83.4	206.8	39,203.4
South Atlantic	150.5	90.5	349.3	31,360.3
East South Central	146.6	72.4	3,485.5	10,099.0
East North Central	131.2	188.3	2,768.7	33,420.4
West North Central	12.3	35.5	4,642.9	15,980.3
West South Central	2.5	0.4	100,369.3	25,476.3
Mountain	34.4	21.6	14,846.8	8,717.2
Pacific	1.8	4.1	18,395.1	24,790.2
U.S. Total	560.9	501.4	145,064.4	233,209.2

[a] Source: U.S. Department of Interior, United States Energy Fact Sheets by State and Region, 1971, Washington, D.C., February 1973.

[b] Based on United States Census Regions defined as follows:

New England: Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, Vermont
Middle Atlantic: New Jersey, New York, Pennsylvania
South Atlantic: Delaware, Florida, Georgia, Maryland, District of Columbia, North Carolina, South Carolina, Virginia, West Virginia
East North Central: Illinois, Indiana, Michigan, Ohio, Wisconsin
East South Central: Alabama, Kentucky, Mississippi, Tennessee
West North Central: Iowa, Kansas, Minnesota, Missouri, Nebraska, North Dakota, South Dakota
West South Central: Arkansas, Louisiana, Oklahoma, Texas
Mountain: Arizona, Colorado, Idaho, Montana, Nevada, New Mexico, Utah Wyoming
Pacific: California, Oregon, Washington, Hawaii, Alaska

Table 3. QUANTITATIVE COMPARISON OF POTENTIAL WASTE OIL FUEL SUPPLY RELATIVE TO RECENT FOSSIL OIL AND COAL FUEL PRODUCTION AND CONSUMPTION TRENDS IN THE UNITED STATES

	Fossil fuel consumption			Range estimate: present waste oil energy potential supply[c] (trillion BTU)	Range estimate: waste oil fuel energy as a percentage of fossil fuel energy
Year	Type and category of fuel use or production	Coal: million tons Oil: million gal	Energy consumption (trillion BTU)		
1970	Coal: Total consumption by electric power plants	322[a]	8,050	72[c] 144[c]	0.89 1.79
1970	Oil: Total consumption by electric power plants	13,944[a]	1,992	72 144	3.59 7.17
1971	Coal: Total production in the United States	561[b]	68,605	72 144	0.11 0.21
1971	Oil: Crude oil total production in the United States	145,064[b]	56,901	72 144	0.13 0.25

[a] Source: Federal Power Commission, The 1970 National Power Survey, Part 1, U.S. Government Printing Office, Washington, D.C., December 1971, p. I-4-2.

A gallon of fuel oil was assumed to produce approximately 142,850 BTU of energy, calculated from averaging the heat of combustion values for distillate and residual fuel oils, as reported in American Petroleum Institute's Petroleum Facts and Figures, 1971 Edition, p. 589.

A ton of coal was assumed to produce 25 million BTU of energy using the same API reference.

[b] Source: U.S. Department of the Interior, United States Energy Fact Sheet by State and Region, 1971, Washington, D.C., February 1973.

[c] Source: Based on a potential waste oil supply range estimate of 500 to 1,000 million gallons per year as calculated in Table 1 of this report.

A gallon of waste oil was assumed to produce 143,330 BTU of energy as reported in "Final Report of the API Task Force on Used Oil Disposal," American Petroleum Institute, New York, May 1970, which reported a heat of combustion value for waste oil of 19,132 BTU/lb of oil.

Quality characteristics of untreated waste vehicle oils may vary widely due to the heterogeneous sources and types of vehicle lubricating oils. Automotive lubricants, for example, include crankcase oils, transmission fluids, differential gear lubricants, hydraulic oil and small quantities of solvents, originating from diverse sources. Since automotive lubricants are highly refined petroleum products, their original character is compatible with efficient combustion. Waste oils have exhibited their fuel potential in various combustion tests and in selected cases of routine usage. Significant uncertainty, however, exists concerning the continued use of waste oil fuels in terms of combustion equipment operation and maintenance impacts, and air pollution emissions from this heterogeneous mixture of oils containing a number of oil and gasoline additives and gasoline combustion products. Large amounts of water, sediments, and inorganic residues including ash and metallic constituents in waste lube oil which cannot be combusted require detailed evaluation for defining the acceptable range of waste oil fuel supply qualities. Sections V, VI, and VII, respectively (pages 48, 61, and 75, respectively) report on detailed investigations undertaken by GCA to evaluate: (1) vehicle waste oil chemical and physical properties, (2) technical feasibility and impacts of combustion, and (3) environmental impacts upon waste oil combustion.

In context to the foregoing supply quality considerations, a range of alternate waste oil fuel products may be marketed based on the extent of oil reprocessing and nature of fuel combustion. The form of the final fuel product may be arrayed around two major options:

1. Waste oil fuel in untreated, recovered or settled forms.

2. Waste oil fuel derived from reprocessing or pretreatment to certain quality specifications using chemical or physical processes.

A second category of trade-offs then arise, related to the specific form of combustion to include:

1. Combusting of waste oil fuel alone

2. Blending of waste oil in various admixture ratios (0 to 100 percent) with virgin fossil coal or oil fuels.

Associated with this range of waste oil fuel products is a range of market prices reflecting the degree of reprocessing. The ultimate user cost is a combination of this direct market supply price and costs incurred in the combustion of the oil.

Supply Price of Marketable Waste Oil Fuels

Fuel energy supply prices reflect production input resource costs, product quality, delivery charges, demand levels, and related interfuel competitive factors. For preliminary waste oil fuel marketability review, the supply price of untreated waste oil must be comparable to existing fuel energy prices or preferably be lower in unit cost to offset the greater risk associated with combustion of waste oil fuel derivatives. Table 4 provides such a preliminary overview of recent market prices of various fossil fuel types and quality grades in the United States, and supply price ranges for untreated or settled waste vehicular oil in the New England region.[8] Due to recent demand-supply imbalances in this nation, fuel prices have increased dramatically in the United States and throughout the world. The average price for residual (grade No. 6) fuel oil, for example, rose about 12 percent during the last half of 1972.[8] Even more dramatic, fuel supply shortages in late 1973 provoked by non-availability of foreign supplies, witnessed over a 100 percent increase in fuel costs for the year, and over 12 percent increase in overall fuel costs in December 1973 alone, as reported by the U.S. Bureau of Labor Statistics.

Comparative fuel costs, therefore, show a large competitive advantage for untreated waste oil today, as shown in Table 4. Average prices for untreated waste oil in December 1973 were only about 30 percent of distillate fuel oil prices, and 40 percent of residual oil supply prices. This represents a significant reversal of the situation in 1969 when waste oil was equal to or greater than the average price of all fuel oils purchased by electrical power plants. Waste oil supply prices vary regionally, but currently are well below virgin oil prices, leaving a large cost margin for pretreatment and reprocessing to meet quality specifications.

This waste oil supply analysis provides a partial view of the potential marketability of waste oil fuel reuse. Equally important is the market demand side of the picture directing the focus of attention on potential waste oil fuel users: their number, spatial distribution, and product requirements. This interplay of demand factors appears next followed by a review of institutional factors and legal requirements placing a third layer of constraints on the potential reuse of waste oil as a fuel, thereby directing the report analysis.

DEMAND FOR WASTE OIL DERIVED FUELS

Demand for energy resources in the United States has dramatically increased in the past decade, impacting all major markets and types of energy sources. The two largest consuming sectors of energy in the economy are industrial and electrical generation. This demand analysis, therefore focuses on steam-electric power plants and various industrial installations due to their large fuel requirement for energy generation, space heating, and/or process steam; and where on-site combustion units are readily available to handle waste oil fuels. In addition, preliminary investigations revealed that several electrical utilities and industrial firms are presently using, or testing for use, waste oil as a blended fuel, mixing it with fuel oil or spraying it over coal. This information served to sharpen the direction of potential demand analysis.

Table 4. SUPPLY PRICE COMPARISON OF FOSSIL COAL AND FUEL OILS WITH UNTREATED WASTE OIL: RECENT TRENDS

Time period	Fossil fuel type	Price per million Btu (cents)	Price per gallon (cents)	Waste oil price as percentage of fossil fuel price[g]	
				June 1973 price ratio	December 1973 price ratio
1969	Average: all fuel oils[a]	34.5	4.6	101.4	156.6
Sept.-Dec. 1972	Coal greater than 3 percent sulfur[b]	34	NA	102.9	158.8
Sept.-Dec. 1972	Coal between 1 and 3 percent sulfur[b]	39	NA	89.7	138.5
Sept.-Dec. 1972	Coal less than 1 percent sulfur[b]	42	NA	83.3	128.8
Sept.-Dec. 1972	Average price of all coals[b]	37.3	NA	93.8	144.8
Sept.-Dec. 1972	Residual oil with greater than 2 percent sulfur[b]	41	6.4	85.4	131.7
Sept.-Dec. 1972	Residual oil between 0.5 and 2 percent sulfur[b]	55	8.2	63.6	98.2
Sept.-Dec. 1972	Residual oil less than 0.5 percent sulfur[b]	68	10.2	51.5	79.4
Sept.-Dec. 1972	Distillate oil less than 0.1 percent sulfur[b]	82	11.4	42.7	65.7
June 1973	Residual oil less than 0.5 percent sulfur[c]	84.2	12.6	43.7	67.5
June 1973	Residual oil between 0.5 and 1 percent sulfur[c]	75.5	11.3	48.7	75.2

Table 4 (continued). SUPPLY PRICE COMPARISON OF FOSSIL COAL AND FUEL OILS WITH UNTREATED WASTE OIL: RECENT TRENDS

Time period	Fossil fuel type	Price per million Btu (cents)	Price per gallon (cents)	Waste oil price as percentage of fossil fuel price[g]	
				June 1973 price ratio	December 1973 price ratio
Dec. 1973	Residual oil less than 0.5 percent sulfur[d]	140.3	20.0-22.0	26.2	40.5
Dec. 1973	Residual oil between 0.5 and 1 percent sulfur[d]	129.9	18.8-20.1	28.6	43.7
Dec. 1973	Distillate oil[d]	195.8	16.6-37.7	20.0	31.3
June 1973	Untreated waste oil[e,f]	35	5-6	NA	NA
Dec. 1973	Untreated waste oil[f]	54	8-9	NA	NA

[a] "As Burned" Cost of Fuel Oil reported in the following reference: Federal Power Commission, The 1970 National Power Survey, Part 1, December 1971, p. I-4-2.

[b] Federal Power Commission "Monthly Report on Cost and Quality of Fuels for Steam Electric Plants," Questionnaire Form 423, 1972.

[c] Market quotation from several fuel oil dealers in the Massachusetts region, specifically the quotations were No. 6 grade oil (1.0% sulfur) at $4.74/bbl, and No. 6 (0.5% sulfur at $5.29/bbl, received in June 1973.

[d] December 1973 market value quotations from Platt's Oilgram News Service, applicable for costs in the United States.

[e] GCA Technology Division, Study of Waste Automotive Lubricating Oil as an Auxiliary Fuel to Improve the Municipal Incinerator Combustion Process, February 1973, p. 60.

The approach employed in this waste oil fuel demand/consumption evaluation follows a sequence of stages to include: (1) literature and statistical survey of steam-electric power plants and major industry groups, (2) comprehensive questionnaire development and distribution to potential industrial and electric utility waste oil fuel users, and (3) personal communications, field interviews and site investigations to prepare detailed case studies of firms routinely combusting waste oil, or testing and analyzing waste oil for potential fuel use.

Fossil Fueled Steam-Electric Power Plants

The electrical power industry is the largest industry in the United States in terms of capital assets, and this industry accounts for about 25 percent of the nation's total energy consumption in the form of coal, oil, and natural gas.[11] Fossil fueled steam-electric power plants are the keystone of the electrical power industry, currently accounting for approximately 76 percent of the nation's total generating capacity and more than 80 percent of the actual electricity generated.[9] The Federal Power Commission predicts that the growth in electricity consumption will continue at a doubling rate every 10 years, or at an annual rate of 7.2 percent. Although increasing reliance on nuclear power and other sources of energy will occur, fossil fuels will remain as significant energy sources for electrical power generation. As previously shown in Table 3, if all the waste oil presently being generated were available for fuel reuse, this total fuel energy potential would represent 1 to 2 percent of the total coal energy, and 3 to 7 percent of the total oil energy consumed by electrical power plants in 1970. Thus the total consumption of waste oil as a supplemental fuel source is well within the capacity of the electrical power industry's fuel demand.

The rapidly expanding energy requirements of the electrical power industry and other consuming sectors is placing increasingly greater demands on domestic and foreign fuel supplies, particularly petroleum-based fuels. One effect of this expanded demand is increased reliance on imported fuels, demonstrated by the fact that in 1972 the United States imported 28 percent of the petroleum consumed: up from 18 percent in 1960.[11] The U.S. Department of Interior reports that domestic natural gas and petroleum will require increasing supplementation to meet demands from electrical power plants and other consumers.[12] The acuteness of the problem for petroleum fuels is illustrated in Table 5, which outlines the domestic petroleum supply as a percentage of total demand, and the required supplemental supplies to meet rising demand.

Table 5. PETROLEUM ENERGY DOMESTIC SUPPLY ENVISAGED AND REQUIRED SUPPLEMENTATIONS TO MEET RISING DEMAND PROJECTIONS[a]

Supply components to meet total U.S. demand	Year				
	1971	1975	1980	1985	2000
Domestic supply as percentage of total U.S. consumption	74.0	63.1	56.3	46.6	29.7
Supplemental supply percentage of total U.S. consumption	26.0	36.9	43.7	53.4	70.3

[a] Source: Dupree, W.G.,Jr., and J.A. West, United States Energy Through the Year 2000, U.S. Department of the Interior, Washington, D.C.: U.S. Government Printing Office, December 1972

Due to recent export policy changes of Middle Eastern oil supplying nations, the United States has announced a new energy goal of reversing the trend of increased fuel oil imports and attaining an internal self-sufficiency to balance demand and supply of fuels. This will require expanded domestic production, energy conservation, and development of new energy and fuel supply forms. Reuse of waste oils as fuels in electrical power generation and other uses, therefore, is consistent with previously established environmental pollution control objectives and promotes energy conservation, now under critical national concern.

In addition to assessing the total capacity and therefore aggregative demand potential of steam-electric power plants for waste oil fuel, the existing and changing spatial distribution of fossil fueled power plants has important implications toward the regional pattern of waste oil fuel reuse feasibility. Figures 1 and 2 provide a present and projected spatial mapping of major steam-electric power production centers in the continental United States. Both fossil fueled and nuclear powered facilities are included in this mapping of major steam centers, but the distribution of fossil fueled plants is rather uniformly spread over the steam generating centers. One general conclusion from the projected spatial mapping at major steam generating centers is that potential waste oil fuel users appear to exist in most major metropolitan regions of the nation, where vehicle crankcase oil supplies are concentrated. This may be deduced by comparing the estimated waste lubricating oil annual supply (Appendix A) to the distribution of power plants shown in Figures 1 and 2. The total number of fossil fueled electric generating units in 1970 was 3400, consisting of 1265 coal-fired units, 1045 oil-fired units, and 990 gas-fired units.[13]

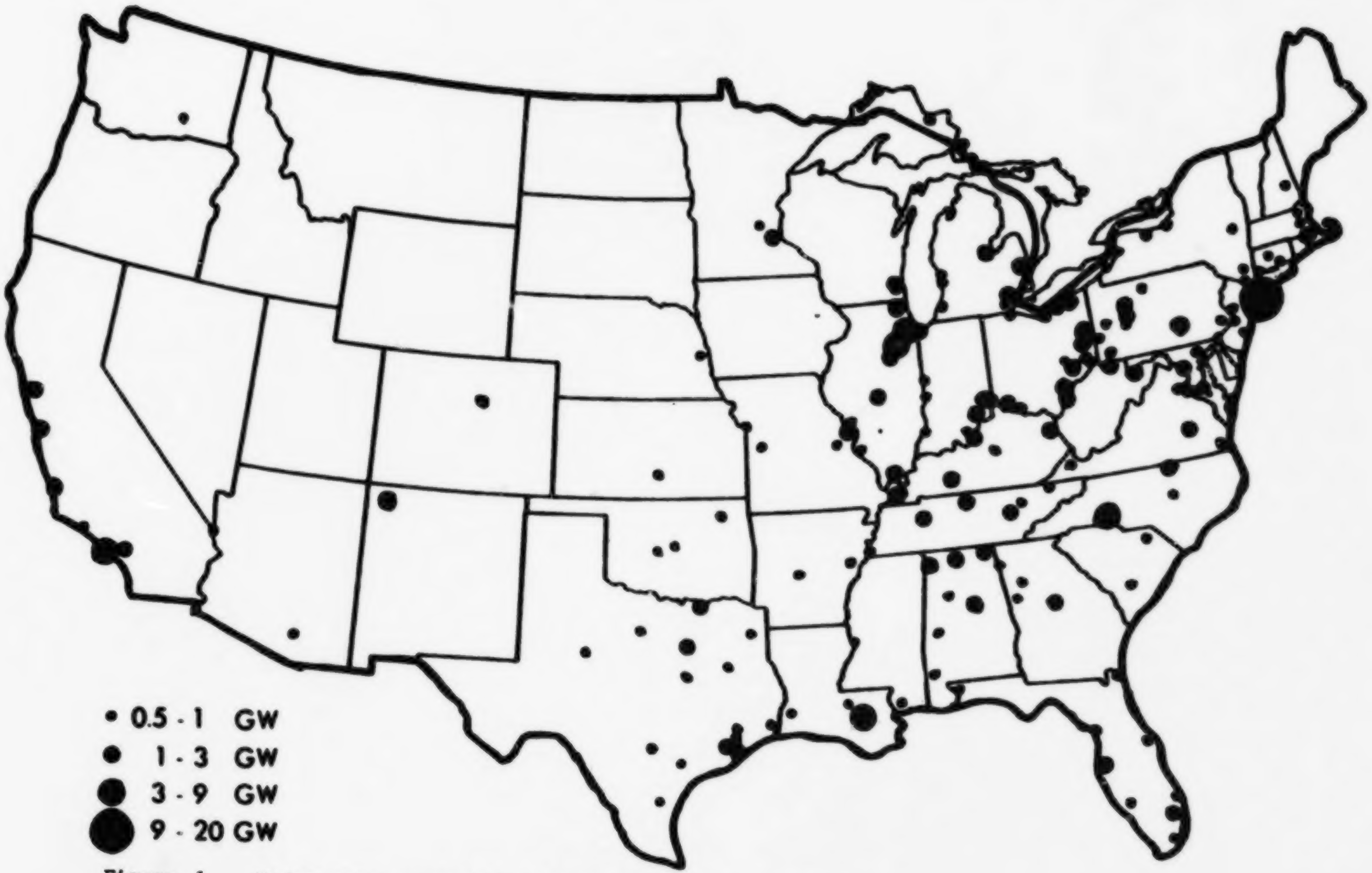
● 0.5 - 1 GW
● 1 - 3 GW
● 3 - 9 GW
● 9 - 20 GW

Figure 1. Major steam generating electrical power production centers in the continental United States, 1970, including both fossil fueled and nuclear powered facilities.[9]

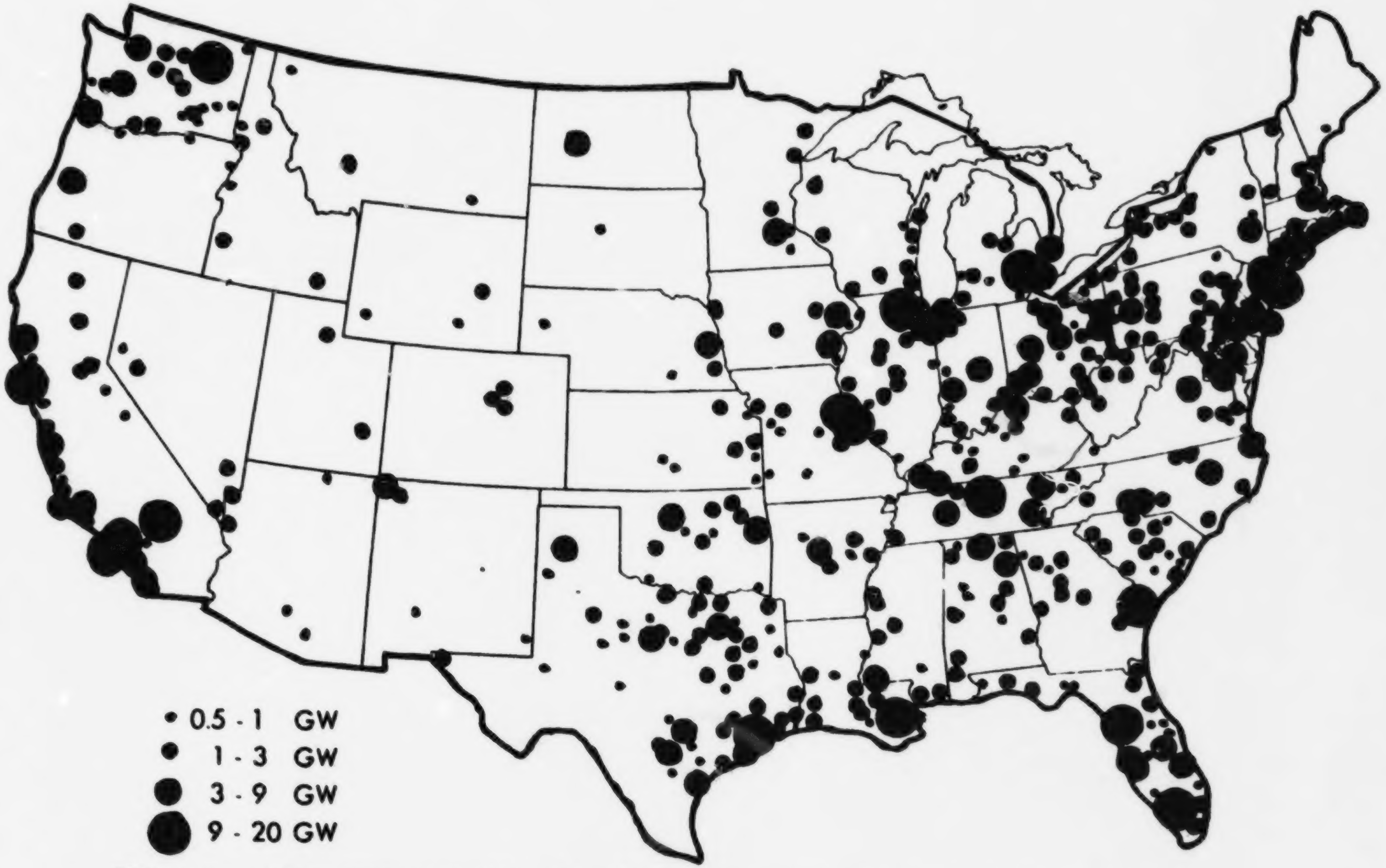
0.5 - 1 GW
1 - 3 GW
3 - 9 GW
9 - 20 GW

Figure 2. Major steam generating electrical power production centers in the continental United States, projected to 1990, including both fossil fueled and nuclear powered facilities.[9]

The spatial distribution of fossil fuel consumption by major class of fuels utilized in steam-electric power plants is graphically exhibited in Figure 3. While each fossil fuel type has some market in most regions of the nation, individual fuels usually have a competitive advantage in any one region, with each region tending to have one dominant fuel. From a more careful analysis of these regional fuel consumption trends, those regions in which coal and fuel oil use are significant cover the Eastern and Western seaboards, and therefore imply potential waste oil marketability in large metropolitan sectors of the nation. In recent years, the trends in fuel consumption have been particularly influenced by environmental pollution control regulations governing ash and sulfur contents in fuels combusted; and by dramatic shifts in domestic and foreign fossil fuel supplies and resultant market price changes. These factors have produced major structural changes in the steam-electric utility industry in certain regions, resulting in conversion of existing plant facilities and construction of new power generating centers. These trends demonstrate the flexibility and fuel switching and modifying capabilities, and therefore potential adaptability of the steam-electric industry to use waste oil fuel blends.

Potential Industrial Demand for Waste Oil Fuels

The industrial sector of the economy is presently the largest annual consumer of energy in the United States, using about 30 percent of the nation's energy input.[12] Most industrial installations require fuel for energy generation, space heating, and/or process steam. These fuel input requirements vary widely between industry categories and among firms within one industry. Table 6 provides a cross sectional breakdown of coal and oil consumption by major industry groups in 1972. The industrial group breakdown utilized is the Standard Industrial Classification (SIC) developed by the U.S. Department of Commerce.[14] Appendix B of this report contains a more detailed and regional accounting of coal and oil fuel consumption by major industrial group (SIC category).

Relative to steam-electric power plants, private industrial firms are more heterogeneous in character, requiring a greater latitude in fuel logistical and utilization considerations. Although the total potential supply of waste oil fuel is small compared to total industrial fuel demand, a wide variety of waste oil fuel use options exist for any one industrial firm location based on fuel availability and cost alternatives, process input requirements, environmental pollution control regulations, and related factors.

Beyond the data base on gross fuel consumption patterns, several industrial plant operating factors have been analyzed as further criteria in identifying potential industrial users of waste oil fuels. These criteria include: (1) particulate matter emission control technology employed by alternate industrial processes, and (2) empirical information concerning industrial firms presently combusting waste oil derived fuels, and firms conducting waste oil combustion testing for potential routine usage of these fuels.

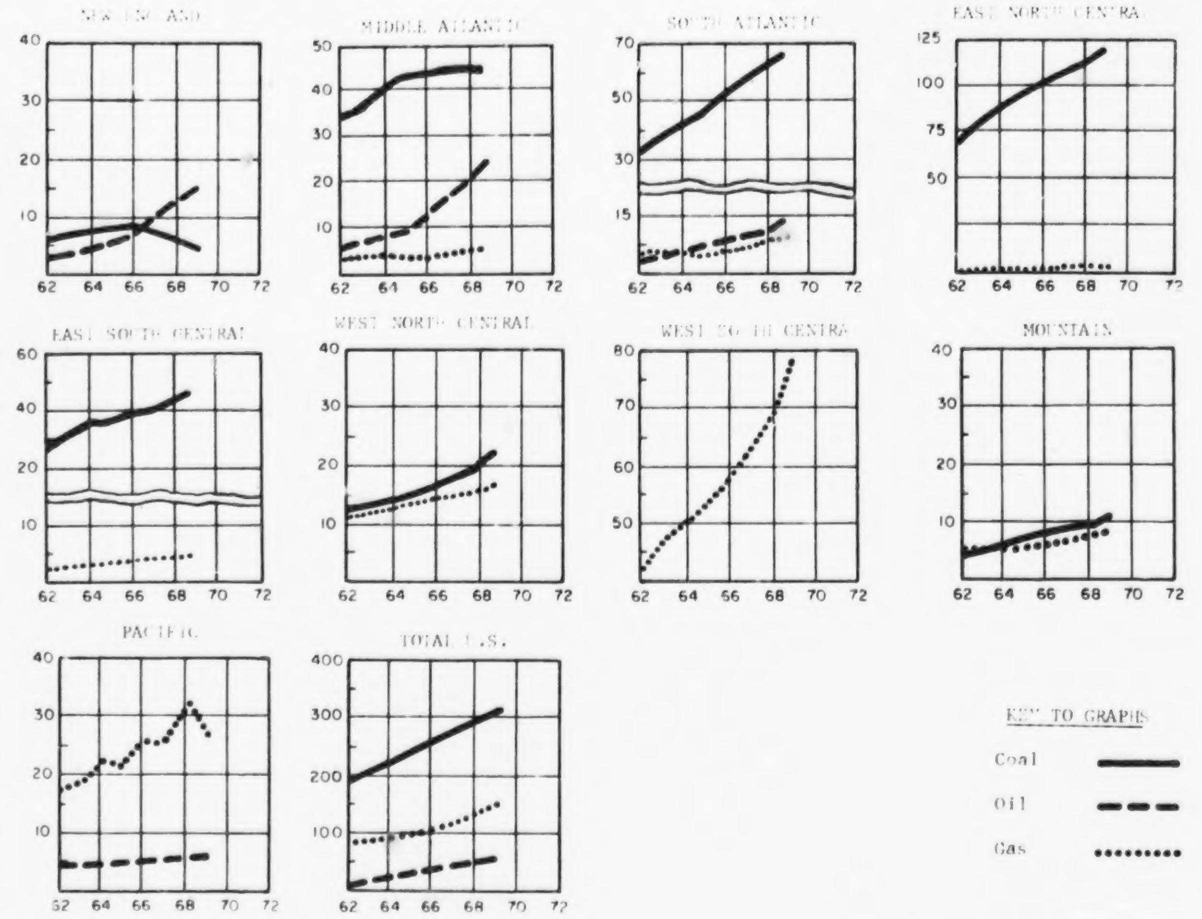

Figure 3. Spatial distribution of fossil fuel consumption trends by Steam-Electric Power Plants in the United States.[1] (millions of coal equivalent tons vs. year)

Table 6. QUANTITY AND COST OF PURCHASED FOSSIL FUELS BY MAJOR U.S. INDUSTRY GROUP (SIC CODES) IN 1972[a]

SIC code	Major industrial group	Total cost $ million	Fossil fuel quantity	
			Coal (short tons)	Oil (1,000 bbls)
20	Food and kindred products	464.7	4,456.1	20,763.1
21	Tobacco manufacturers	9.5	173.3	704.0
22	Textile mill products	159.7	545.8	11,202.4
23	Apparel and related products	33.3	146.7	1,159.8
24	Lumber and wood products	154.7	184.3	6,371.6
25	Furniture and fixtures	30.2	225.1	940.2
26	Paper and allied products	562.4	9,439.0	64,588.6
27	Printing and publishing	46.0	17.6	1,323.6
28	Chemicals and allied products	894.0	18,323.6	33,861.9
29	Petroleum and coal products	447.6	358.4	13,945.0
30	Rubber and plastics products	89.8	1,243.9	5,279.3
31	Leather and leather products	16.6	115.6	1,271.9
32	Stone, clay, and glass products	572.3	9,708.7	19,540.9
33	Primary metal industries	1,151.4	9,462.4	36,935.1
34	Fabricated metal products	178.2	649.6	4,854.6
35	Machinery, except electrical	172.5	1,214.9	5,934.7
36	Electrical machinery	116.4	685.9	5,251.0
37	Transportation equipment	178.3	2,609.7	6,760.7
38	Instruments and related products	33.9	696.9	1,771.6
39	Miscellaneous manufacturing	49.1	135.1	3,207.5
	All industries total	5,360.6	61,392.6	245,667.2

[a] Source: U.S. Department of Commerce, Bureau of the Census, 1972 Census of Manufacturers: Fuels and Electricity Energy Consumed, Special Report Series, Washington, D.C., U.S. Government Printing Office, July 1973.

Industrial demand for waste oil derived fuels will be influenced by both technical and environmental impact considerations upon combustion. Environmental impacts are of central concern due to the possibility of high ash and metallic constituents in vehicular waste oil, resulting in fine particle emissions of materials potentially harmful to human health upon combustion. A range of waste oil pretreatment and fuel use options exist to mitigate these undesirable impacts, including (1) pretreatment of waste oil to attain certain quality specifications, (2) blending of untreated waste oil with virgin oils to dilute undesirable constituents, (3) process modifications and stack gas emission control techniques to reduce air pollution emissions, and (4) combination of these alternate fuel product and use alternatives.

Following sections of this report focus on technical and environmental impacts of vehicle waste oil combustion and alternate means of mitigating these impacts. The primary objective of the analysis is to identify the range of fuel use methods requiring minimal pretreatment and handling of waste oil to meet environmental and technical constraints with minimal costs and residue disposal problems. The criterion of installed emission control technology employed by industrial processes serves to identify selected industrial firm categories as prime potential users of minimally pretreated waste oil fuel products. Since waste oil demand will be principally in the form of a supplemental fuel, installed particulate matter control technology enhances the feasibility of waste oil fuel usage and removal of undesirable particle emission without a large additional outlay of capital for control hardware installation.

A third criterion useful in identifying potential industrial firm demand for waste oil fuels is present or past combustion experience with waste oil. Literature survey and information collection on waste oil reveals that a number of firms have first-hand experience at waste oil fuel usage. One report, for example, identified an industrial firm, Allied Chemical Corporation, as a waste oil fuel consumer, combusting over 8 million gallons of waste automotive lubricants per year at one plant site.[16] These reports of waste oil combustion provide tangible evidence on the fuel use feasibility and potential demand of waste oil fuels, and served to guide the direction of empirical investigations undertaken in this study.

Direct Monitoring of Potential Demand: Questionnaire Survey and Case Study Analyses

Empirical investigations were conducted at various stages in this study to provide a primary data base of information relating to potential waste oil fuel marketability and underlying technical, environmental, and economic factors associated with vehicle waste oil reuse as a fuel. This direct monitoring of potential waste oil fuel users served to verify and expand literature and statistical analyses of waste oil fuel marketability, and gauge use feasibility from the viewpoint of actual and potential fuel users.

Several primary data collection techniques and empirical analysis approaches were employed to include: (1) questionnaire distribution to potential electric utility and industrial firm users of waste oil fuels, (2) field site visits and personal interviewing at selected electric power plants and industrial firms, and (3) information interchanges through various communications media.

Mail questionnaire development and distribution to potential waste oil fuel users was undertaken to evaluate current views on the feasibility and methods of waste fuel usage, fuel product requirements, demand price and demand quantity at the user level: steam-electric utilities and selected industrial process users. Two questionnaire formats were prepared to survey these potential waste oil fuel consumers. One questionnaire, distributed to 205 electric utility companies covering all 50 states, sought information pertaining only to usage of waste oil fuels, with supplemental information for each firm on existing fuel use and installed air pollution emission equipment being obtained from the Federal Power Commission.*

A second, more extensive questionnaire format was developed to monitor waste oil fuel use feasibility as viewed by a cross-section of industrial firm categories. Information was also solicited concerning existing fuel use and combustion equipment characteristics, air pollution emission control capabilities and government regulations on process operations. Survey distribution totaled 562 firms covering seven of the 20 major industrial groups listed in Table 6 to include: (1) lumber and wood products, (2) paper and allied products, (3) chemicals and allied products, (4) petroleum and coal products, (5) rubber and plastics products, (6) stone, clay and glass products, and (7) primary metal industries. Rationale for selecting industrial firm types for monitoring involved synthesizing the criteria previously outlined in identifying potential demand sources, namely: (1) existing fuel energy consumption requirements, (2) installed air pollution emission control technology, and (3) present or existing waste oil combustion experience.

Questionnaire responses received show a favorable attitude toward waste oil fuel usage by electric power plants, and mixed responses from alternate industries, as reported in Table 7. Those responding affirmatively to use feasibility generally qualified their response by citing a range of pretreatment or property changes required before a

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*Data obtained from Federal Power Commission questionnaire Form 67, titled "Steam-Electric Plant Air and Water Quality Control Data for the Year Ended December 31, 1972."

Table 7. WASTE OIL FUEL USE QUESTIONNAIRE: SELECTED RESPONSES MONITORING POTENTIAL DEMAND BY ELECTRICAL UTILITIES AND VARIOUS INDUSTRIAL FIRMS[a]

Questionnaire distribution user categories		Waste oil fuel use feasibility assessment		Form of waste oil fuel usage		Price willing to pay				Quantity demanded for potential use[b]	
						Untreated		Pretreated			
						Average cents/gal	Range cents/gal	Average cents/gal	Range cents/gal	Average gal/day	Range gal/day
Steam-electric utilities	Response	Yes	No	Blended with oil	Mixed with coal	7.1	0-15	8.3	0-15	19,000	250-100,000
	Number responding	49	19	39	14	19	19	20	20	34	34
Mixed industrial firms	Response	Yes	No	Blended with oil	Mixed with coal	5.3	0-10	13	2-20	32,900	250-200,000
	Number responding	17	14	7	2	9	9	5	5	34	34

[a] See Appendix C for questionnaire formats and summarized tabulation of responses.

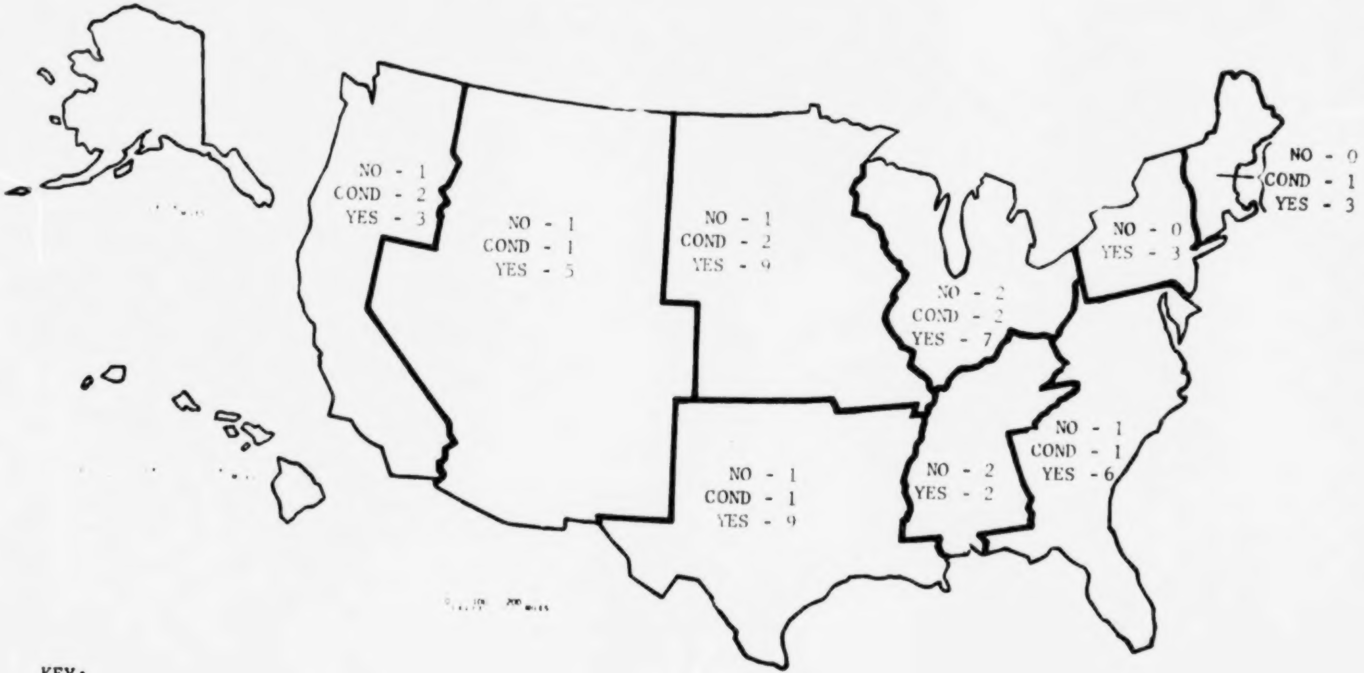
[b] The size of the power plants was not discernable from the questionnaires. In some cases respondents were electrical utility company representatives expressing potential demand for several power plant locations under their control.

final waste oil fuel product would be used. Waste oil fuel would be used as a supplemental fuel to be blended with fuel oil or mixed with coal, with oil blending being the most frequent response. Potential demand price ranged widely, averaging 5-7 cents for untreated waste oil fuel, and 8-13 cents for various pretreated waste oil fuel products as specified by the responding firms. Likewise, quantity demand on a daily basis ranged widely, averaging around 19,000 gallons/day for steam-electric power plants and 32,000 gallons/day for industrial firm respondents. A copy of the questionnaire distributed and a complete summary of responses appear in Appendix C for electric utilities and Appendix D for potential industrial firm users.

In overview, potential demand for waste oil fuels by electric power plant operations was identified in all census regions of the nation. The distribution of survey response by census region is graphically illustrated in Figure 4. A rather irregular distribution of demand was revealed in the small fraction of questionnaires returned by various industrial firms (11 percent response). Combining the response pattern from electrical power plants and various industrial firms, a large potential demand for waste oil derived fuels was indicated, covering many regions of the country. Explicit concern by questionnaire respondents, however, mandated a more comprehensive analysis of technical, environmental impacts of alternative usage patterns, and regulations affecting this mode of waste oil reuse.

Complementing this potential waste oil fuel questionnaire survey, a selected number of electric utility and industrial firm field-site visits and/or operator interviewing was conducted. These investigations produced information used at various stages in this report concerning waste oil fueld combustion alternatives, technical and environmental impacts, and requirements for achieving acceptable fuel products. Information and data obtained through consultation with the following organizations are integrated into this report:

- Electric Utilities
    - Hawaiian Electric Company, Inc.: presently combusting vehicular waste oil fuel on a routine basis with virgin oil at their Waiau Power Plant.
    - Northern States Power Company: presently evaluating waste oil fuel combustion along with coal through extensive combustion testing at their High Bridge Generating Plant in St. Paul.
    - New England Power Systems: a potential user of waste oil fuels.
    - General Electric Corporation, Lynn, Massachusetts, Electrical Power System: a potential user of waste oil fuels.


NO - 1
COND - 2
YES - 3
NO - 1
COND - 1
YES - 5
NO - 1
COND - 2
YES - 9
NO - 2
COND - 2
YES - 7
NO - 0
YES - 3
NO - 0
COND - 1
YES - 3
NO - 1
COND - 1
YES - 9
NO - 2
YES - 2
NO - 1
COND - 1
YES - 6

KEY:

NO: Cannot use waste oil fuels
COND: Conditional yes if composition change made
YES: Can use waste oil derived fuels

Figure 4. Steam-electric utility questionnaire response by census region on potential use of waste oil fuel (see Appendix C for a copy of the questionnaire distributed to 205 electric utility firms, and detailed responses).

- Industrial Firms
  - Allied Chemical Corporation: presently combusting vehicular waste oil at their Solvary, New York, plant.
  - Bethlehem Steel Company, Bethlehem, Pennsylvania: a potential steel plant user of waste oil fuels.
  - Trimount Bituminous Products Company, Everett, Massachusetts: a potential asphalt batch plant user of waste oil fuels.
  - Keystone Portland Cement Company, Allentown, Pennsylvania: a potential Portland cement plant user of waste oil fuels.

In addition, comprehensive combustion and air pollution emission testing results and analysis from vehicular waste oil-virgin fuel blends was obtained through information exchange with the following organization:

> U.S. Army Mobility Equipment Research and
> Development Center, Coating and Chemical
> Laboratory, Aberdeen Proving Ground, Maryland.

This Aberdeen Proving Grounds testing is being conducted to evaluate the feasibility of waste oil fuel combustion for reuse of waste oil derived from large scale vehicle fleet operations of the federal government.

INSTITUTIONAL/LEGAL FACTORS INFLUENCING WASTE OIL FUEL REUSE

The ultimate sale and use of waste oil fuels will be affected by a range of non-market constraints imposed at the local, state and/or national levels. These constraints are the institutional factors through which society and the private market operate: laws, regulations and standard procedures established primarily through governmental legislation; court decisions; public agency actions; and private organization regulations. For purposes of discussions these institutional factors may be divided into several categories: (1) laws and regulations uniquely applicable to waste oils, (2) environmental, management and pollution control activities directly influencing waste oil fuel use, (3) environmental controls indirectly affecting the relative merits of waste oil fuel use, and (4) laws and constraints governing facility operating features of potential vehicle waste oil fuel users.

These institutional factors are numerous and may vary greatly for different regions of the nation. In this discussion the general types of potentially influential factors are enumerated to serve as a guideline in evaluating the potential for waste oil fuel utilization in specified regions. It should be recognized that there is no one form of waste oil fuel product or use alternative which is equally acceptable in every potential use circumstance.

Laws Uniquely Applicable to Waste Oils

An increasing number of laws, particularly at the state level, exist or are proposed to control and manage waste oil at various stages in its lifecycle: storage, collection and transporting, sale of derived waste oil products, and reuse of these products. The basic requirements for storage and blending of waste lubricating oils are similar to those for storing heavy fuel oils,[17] and are evaluated in more detail in Section VIII of this report. Location, construction, and piping of waste oil storage tanks will in most cases be subject to local codes, safety requirements and insurance regulations as applicable for other competitive fuel oils.* Similarly, state and local safety regulations governing the transportation of flammable liquids by tank trucks, pipe lines and other mechanisms also apply, but these regulations are applicable to all petroleum products, and are not unique to waste oil products.

Of more concern from a competitive market viewpoint are specific waste oil management programs initiated by several states. States with comprehensive waste oil management programs include Maryland, Massachusetts and Vermont; and several other states are in the planning stages of such programs.[19] In general, these management plans incorporate storage, transit and land disposal controls into the overall management and pollution control plan. One state, Nebraska, was found to have a law specifically regulating the use of waste oil fuels by stipulating certain quality standards that must be achieved prior to sale of vehicle waste oil derived fuels. The Nebraska law states:

> 66-312.01. Drain oil; definition; sale or use unlawful; violation; penalty. It shall be unlawful for any person to sell or offer for sale or to use drain oil, or a mixture of drain oil and standard commercial fuels, for heating or power fuel purposes unless such drain oil has been reprocessed so as to reduce the combined water and solids content

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*An example of these types of regulation may be seen in The Commonwealth of Massachusetts, Department of Public Safety, Board of Fire Protection Regulations titled, "Rules and Regulations Governing the Keeping, Storage, Manufacture or Sale in Limited Quantities of Flammable Fluids, Solids or Gases."[18]

> to a maximum of one per cent by weight and completely remove highly flammable aromatic hydrocarbons having a flash point of sixty degrees Fahrenheit or less, such as gasolines, toluol, benzol, methyl and ethyl alcohols, acetone, and methyl ethyl ketone.
>
> For the purposes of this section, drain oil shall mean used lubricating oil which has been drained from any internal combustion engine. Any person violating the provisions of this section shall be guilty of a misdemeanor and shall, upon conviction thereof, be punished by a fine of not less than one hundred dollars and not more than one thousand dollars.
>
> Source: Laws 1963,c. 370, § 1, p. 1191.

Other states and localities may have similar laws or may institute them in the future, thereby constraining the quality of waste oil fuels sold and requiring more reprocessing of untreated waste lubricating oil.

At the Federal level, several regulatory actions relating to waste oil and other waste products act to constrain the marketability of certain waste oil derived products such as re-refined lubricating oils. Product labeling regulations, excise tax requirements, and freight rate-scales for recycled waste products discourage the use of recycled oil. These regulations, for the most part, act to restrict the production of waste oil derived lube oils, and not waste oil fuel sales. Indirectly, therefore, these controls act to restrict the range of economically viable reuse options, enhancing the concept of local and regional reuse of waste vehicle oil as a supplemental fuel.

Air Pollution Control Actions Directly Affecting Waste Oil Fuel Combustion

From a total environmental system viewpoint alternate waste oil reuse approaches pose impacts involving interpollutant and intermedia tradeoffs. Waste oil reuse as a fuel for combustion eliminates potential water and land pollution impacts, but potential air pollution problems may result. Since the air resource is the primary media through which pollution impacts will be transmitted from waste oil fuel combusting, air resource management and pollution control actions represent important constraints in the performance evaluation of alternate waste oil fuels.

Two categories of air resource management and pollution control actions require analysis in viewing the regional marketability of waste oil fuels: (1) air pollution controls directly governing the combustion of fuels, and (2) air quality control actions that indirectly influence the competitive position of waste oil fuels relative to alternate fuel sources. The principal air pollutants for which current and anticipated air quality controls measures have direct bearing on waste oil fuel combustion include: (1) particulate matter, (2) lead particles and other potentially hazardous constituents found in lubricating oil additives such as calcium, zinc, barium, magnesium, phosphorus and others, and (3) sulfur oxides.

These air pollution control measures may take several forms at the federal, state, and local governmental levels. At the Federal level, under the Clean Air Act of 1970,[20] control of air pollution from stationary sources generally takes one of three forms: (1) national ambient air quality standards (NAAQS), (2) new source performance standards (NSPS), or (3) hazardous emission standards.* At the state and local levels, stationary source emission standards for existing and new sources have been developed to achieve and maintain the NAAQS. In addition, emission standards for other materials have been established in selected regions. Thus several possible layers of air pollution control regulations may constrain the combustion of waste oil based on the quality levels of the fuel product derived. Based on the typical chemical composition of waste vehicle oil,[21] relatively high in percent ash composed of lead or other metallic constituents, and low in percent sulfur, the emission of particulate matter containing metallic impurities represents the most critical air pollution hazard. Based on the preceding discussion of air pollution control regulations, the following existing or anticipated air quality standards will govern the acceptable quality of waste oil fuel and potential users at the regional level:

- Particulate matter standards:

  1. Federal level: New source performance standards
  2. State and local levels: Emission standards governing the use at both existing and new sources

- Lead and other metallic and inorganic impurities:

  1. Federal level: Hazardous pollutant emission standards governing all sources
  2. State and local levels: Emission standards for both existing and new sources.

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*If the effect on health and welfare is "adverse" or the possibility of their endangerment exists, and the pollution is due to numerous or diverse sources, national ambient standards and/or new source standards should be considered. If the possibility of endangerment of health or welfare exists but sources are not numerous or diverse, new source standards may be the proper option. If the possibility of mortality or serious or incapacitating illness exists, hazardous emission standards may be as appropriate as, or more so than, the other two options.

With these direct environmental constraints in view, Section VII (page 75) addresses the question of potential emissions from untreated vehicular waste oil combustion. This analysis is supported by the detailed chemical and physical characterization of vehicle waste oils reported in Section V (page 46). Waste oil combustion emissions are a function of process size and time. Comparing potential emissions with applicable standards thereby identifies the degree of waste oil fuel pretreatment, stack gas emission control or combined operating changes required to attain acceptable combustion. These fuel product or use changes imply higher waste oil fuel user costs, a restricted range of user applications and a decrease in overall demand of waste oil fuels.

Environmental Control Actions Indirectly Affecting Waste Oil Fuel Marketability

Several air pollution control regulations governing emissions from stationary combustion sources may directly constrain waste oil fuel use as previously outlined. A series of other recent environmental control actions, however, indirectly influence the marketability of waste oil fuel through their impact on fuel users and fuel products. To begin, air pollution emission control requirements have resulted in the installation of stack gas emission control devices at fossil-fueled steam electric power plants and numerous industrial processes involving fuel combustion. Second, concern over sulfur oxide emissions has been translated into both emission standards and fuel-sulfur regulations governing the maximum permissible level or weight percent of sulfur in coal and fuel oils. These two indirect impacts of environmental controls: installation of air pollution emission control technology and fuel sulfur regulations; bear important implications on the demand for waste oil fuels.

Due to air pollution emission control regulations, a wide range of process and stack gas emission control devices is currently being employed by various industries, and this enhances the feasibility of waste oil fuel usage and removal of harmful particle emissions without a large additional outlay of capital for control hardware installation. In general, there are two major categories of air pollution emission control devices presently employed: 1) physical (mechanical and static), and 2) chemical. The total installed cost of emission control devices for electric power plants alone, for example, was inventoried by the Federal Power Commission[23] and reported as of January 1969 to be:

Installed Cost of Equipment	Cost in Millions of Dollars
Mechanical collectors	42.3
Electrostatic precipitators	229.5
Combination of Above	120.7

Thus, there appears to be a large existing particulate matter control potential at power plants, particularly at coal burning units, that may reduce emissions from waste oil fuel combustion thereby reducing

Table 8. RESIDUAL FUEL OIL SULFUR CONTENT LIMITS AS REQUIRED IN SELECTED CITIES AND REGIONS IN THE UNITED STATES

City/region	Effective date	Sulfur limit percentage by weight	Comments
Chicago	1972	1.0	Applicable to space heating industry and all power generation.
Los Angeles and vicinity	1965	0.5	Some utilities required to burn gas when available.
New York	1969	0.37	All users except power plants.
	1970-75	1.0	Power plants.
New Jersey	1971	0.3	All users.
Boston and vicinity	1970	0.5	All users.
Massachusetts, except Boston	1970	1.0	All users.

pretreatment requirements for waste oil and enhancing the fuel use demand potential. It must be recognized that the control efficiency potential is variable for this installed capacity, dependent upon original equipment design, operational performance factors and related variables. A more detailed evaluation of the control efficiency of alternative equipment designs and operational conditions appears in Section VIII (page 89). Other industrial processes also have installed control capacities of these and other more efficient collection systems such as fabric filter baghouse units, with an ability to control fine particle emissions including potentially hazardous metallic constituents of waste oil combustion.

The second category of indirect effects of environmental controls on waste oil fuel use result from sulfur oxide emission regulations and related limitations established on fuel sulfur content in many regions. These controls affect the fuel market in general, and tend to enhance the market demand for recovered waste oils low in sulfur for use as a blended fuel. In many regions of the nation, state and local air pollution regulations and related environmental laws govern the maximum quantity of sulfur (percentage by weight) permitted in various classes of fuel oils and coal. Regulations on fuel sulfur content already exert a significant effect on fossil fuel supply logistics, quality of fuels marketed, and research into alternative methods to attain continuing supplies of fossil fuels. Table 8 provides a synoptic view of selected residual fuel oil sulfur content regulations that have been enacted in recent years by various regional and state environmental quality control agencies in the United States.

Concurrent to implementation of stricter air pollution emission controls governing fuel combustion has been a shift in the demand and consumption patterns of large fuel users toward cleaner fuel products. One result, for example, has been an unprecedented demand increase for residual fuel oil, particularly by electrical utilities to replace coal fueled systems.[24] Another impact has been the conversion of combustion processes to accommodate alternate fuel types. In the New England region, for example, almost twice as much oil as coal was used by electrical power plants in 1968, but as recently as two years earlier, in 1966, more coal than oil was used.[25]

To meet the growing demand for low sulfur residual fuel and alternate low sulfur oil and coal fuels, several options exist to include: 1) use of naturally occurring low sulfur fuels, 2) blending of low and high sulfur oils to attain acceptable quality specifications, 3) desulfurization of high sulfur fuels, and 4) use of flue gas desulfurization systems. A comprehensive analysis of the future supply and demand of low sulfur fuel oil, conducted for the U.S. Environmental Protection Agency,[26] concluded that all these routes are being pursued, and efforts should be made to reduce the detrimental blending of domestic oils which is reducing the availability and increasing the cost of distillate oils for residential usage. From a cost viewpoint, usage of "clean" or lower sulfur fuel is more desirable than installation of costly and experimental stack gas desulfurization systems. Since waste automotive lubricating oils are low in sulfur, use of waste oil fuel blending with higher sulfur fuels appears to be an increasingly attractive procedure. Since a great deal of fuel oil blending has occurred in recent years, the science of fuel blending and methods for implementation are well developed.

As an aid in identifying the regions where sulfur oxide problems are most intense, and therefore where the demand for low sulfur fuel most critical, Figure 5 illustrates the spatial distribution of Priority region classifications established by the U.S. Environmental Protection Agency with regard to sulfur oxides.[16] The annual arithematic mean sulfur oxide secondary ambient air quality standard established by EPA is 60 micrograms per cubic meter ($\mu g/m^3$). Priority I and II regions have air quality in excess of the ambient standards. The spatial distribution of Priority I regions corresponds closely with the spatial distribution of steam-electric power generating centers identified in Figures 1 and 2.

Laws and Constraints Influencing the Operating Characteristics of Potential Waste Oil Fuel Users

A final level of institutional factors that may play a role in waste oil fuel use decisions applies to the operation and management procedures of alternate industrial firms and electric utilities. Private firm operating and production procedures may be governed by a set of standard operating procedures developed by the firm's management or imposed by government regulatory agencies. These factors may influence fuel imput decisions of individual firms or category of potential waste oil fuel users. The case of electric power plants and the influence of public utility commissions on power plant operations in many regions will be reviewed here as an example of how these operating factors might influence waste oil fuel marketability.

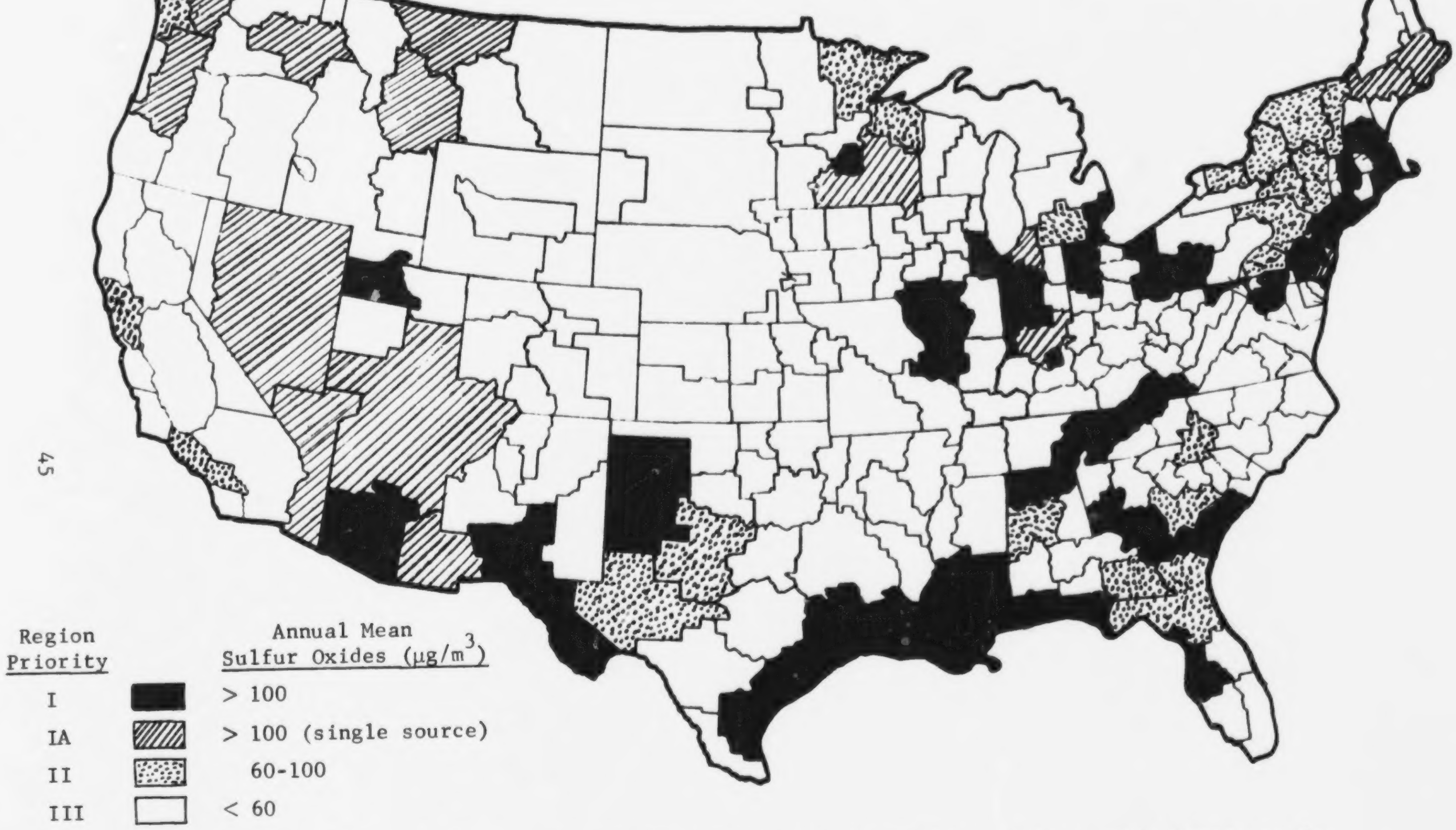
Region Priority
Annual Mean Sulfur Oxides (μg/m³)
I ■ > 100
IA ▨ > 100 (single source)
II ░ 60-100
III □ < 60

Figure 5. Priority of air quality control regions based on ambient sulfur oxide levels as determined by the U.S. Environmental Protection Agency

An examination of the cost structure of the regulated electrical utility industry reveals that three basic inputs are required to produce electric power: 1) fixed equipment investments, 2) fuel, and 3) operation and maintenance. The mix of these inputs differs for alternate types of generating facilities; and for fossiled fuel steam electric plants fuel is a major operating cost, including procurement, transportation, storage and handling.[28] Fuel input and cost decisions are therefore critical factors in efficient production of electricity.

In every state except Texas, there is a public agency authority to regulate utilities, including electrical utilities, but the scope of their jurisdictions vary from state to state.[9] For the electrical utility industry, public utility commissions generally attempt to eliminate supernormal profits and encourage firms to be efficient in serving customers. Since regulatory commissions in most areas of the nation control the service charge or electricity rate, the affect of increased production costs in electricity are highly indeterminate,[29] and one must examine the method of rate control and how production input costs are considered by the regulatory commission.

Utility companies desiring to increase their electric rates based on higher input costs such as capital investment and labor expenses, must receive approval by public utility commissions and/or rate hearing boards in most states. In many regions, however, public utility regulatory agencies have established fuel adjustment clauses which permit firms to pass added fuel costs on to their customers directly, without rate hearings or approval. Order 12096 of the Massachusetts Department of Public Utilities, for example, concerning rate schedules of electric companies, states:

> "Where conditions require a change in the base cost or fuel adjustment factor, we consider it good regulation unless circumstances indicate otherwise to permit a utility to make such change in its base rate as will result in the same revenue as before the change, without formal rate proceedings..."[30]

In order to determine the specific number of utility commissions employing such fuel adjustment clauses, 51 commissions having jurisdictions over electric utilities, covering all states except Texas, were surveyed.* Of the 24 commissions responding to this survey, the following results were obtained:

- 17 Commissions had some form of fuel-adjustment clause
- 3 Commissions had no fuel adjustment provisions
- 4 Commissions did not state their position.

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*Identification of these commissions may be found in the following reference: Electric World, Directory of Electric Utilities, 1971-72, 80th Edition, New York: McGraw Hill, 1972.

Upon examining various fuel adjustment clauses, it was found that they are variable, governing the electricity charge rates for alternate classes of service including industrial, commercial, residential, and others. In general, regarding air pollution considerations, these fuel adjustment clauses tend to provide incentives to electric utility companies to be less capital intensive and use higher cost, cleaner fuels, which can be passed directly on to consumers, rather than use add-on control equipment required to meet air pollution emission regulations, thus by-passing formal rate hearing board review. This operating constraint, therefore, may influence both the magnitude of demand for waste oil fuels, and the quality of fuel product desired by electric utilities. The relatively low sulfur content of waste oils enhances their magnitude of demand for use as blended fuels requiring no additional stack gas control equipment to meet sulfur emission regulations. In terms of quality of waste oil fuel products demanded, regulated utilities may favor treated waste oil fuels, free of undesirable air pollution combustion products requiring additional particle emission controls, and free of constituents affecting equipment maintenance.

SECTION V

CHARACTERIZATION OF UNTREATED WASTE OIL

In this study, GCA is considering two major waste oil fuel use options; (1) blending waste oil with other fuel oils prior to combustion and (2) combusting waste oil in conjunction with coal. This section compares the chemical and physical properties of waste oils to those of virgin fuels (oil and coal). These comparisons will serve as essential inputs for evaluating the technical feasibility (Section VI) and environmental acceptability (Section VII) of burning waste oil/virgin fuel blends.

Waste oil lubricants are composed of a heterogeneous group of oils, including waste crankcase oil, transmission fluids, differential gear lubricants, hydraulic oils, and small quantities of solvents. Waste crankcase oils usually constitute the major portion of waste oil lubricants. These waste crankcase oils contain some or all of the following substances; (1) a moderate amount of sulfur which is inherently present in lubricating oils, (2) many different functional additives, (3) iron "fines" which result from engine fretting and wear, (4) gasoline components, oxidized materials, atmospheric dust and combustion products (i.e., water) which are transferred via "piston blowby", (5) sedimentary materials which were formerly internal engine deposits, and (6) water and other contaminants which are introduced into waste oil storage tanks.

A detailed characterization of waste oil lubricants, virgin fuel oils and virgin coals are presented in Appendix E. Figure 6 summarizes the findings in Appendix E and serves as the basis for the following discussion. If a particular fuel is not mentioned below in a property comparison, it is either because values for that property were not reported in the information sources utilized or because the property being considered is not relevant to that particular fuel (i.e. specific gravity for coal).

GRAVITY (°API AT 60°F)

Gravity expressed as °API is a commonly employed inverse measure of oil density. The °API gravity range found for waste oil lubricants lies between the values of 20.0 and 27.9. As shown by Figure 6(a), this range lies within the gravity ranges found for both number 4 (15.0-30.0 °API) and low sulfur residual (13.0-33.0 °API) fuel oils. Waste oil lubricants are generally less dense than residual oils (0.3-26.0 °API) and more dense than distillate oils (30.2-45.3 °API).

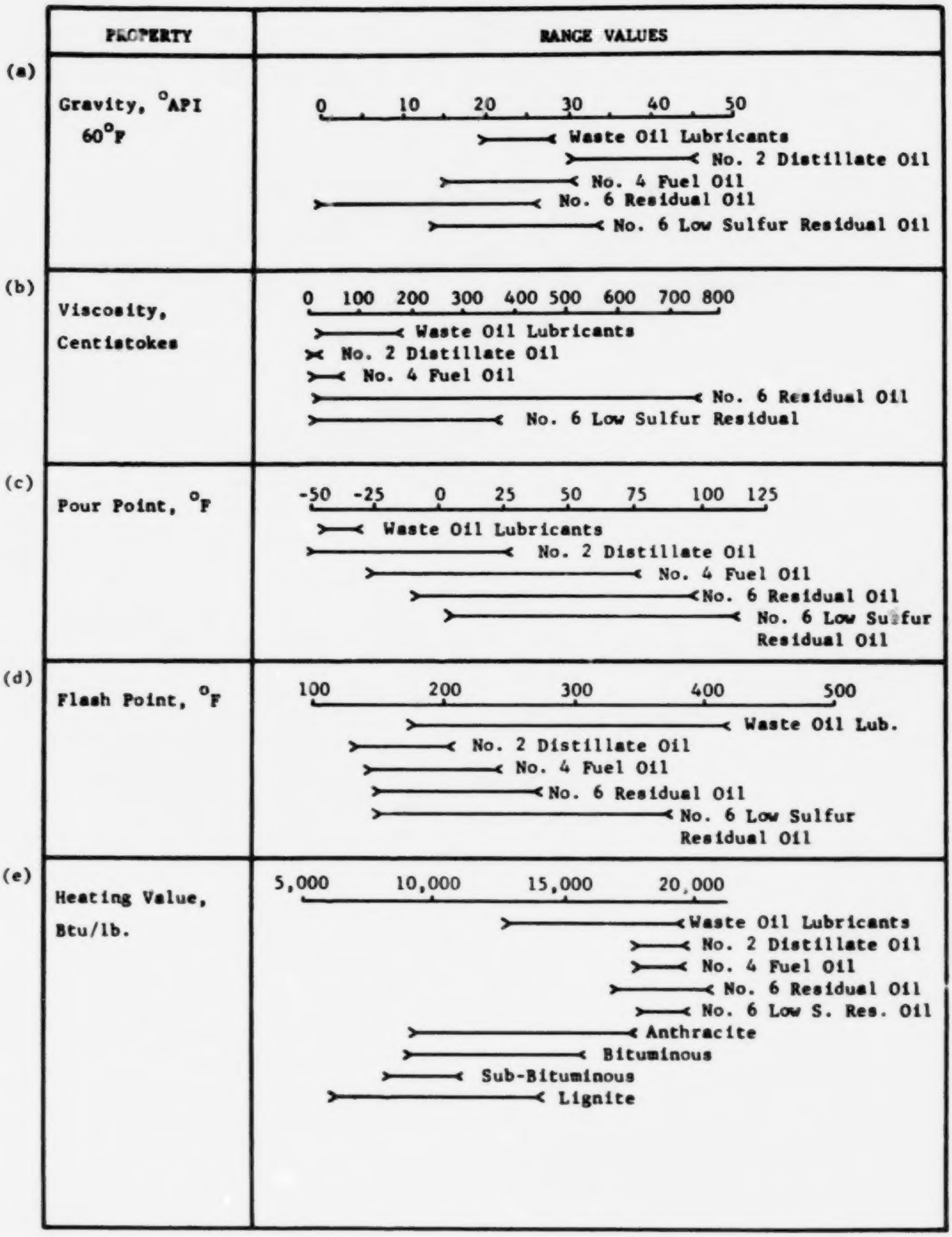

Figure 6. Comparison of waste oil and virgin fuel property ranges

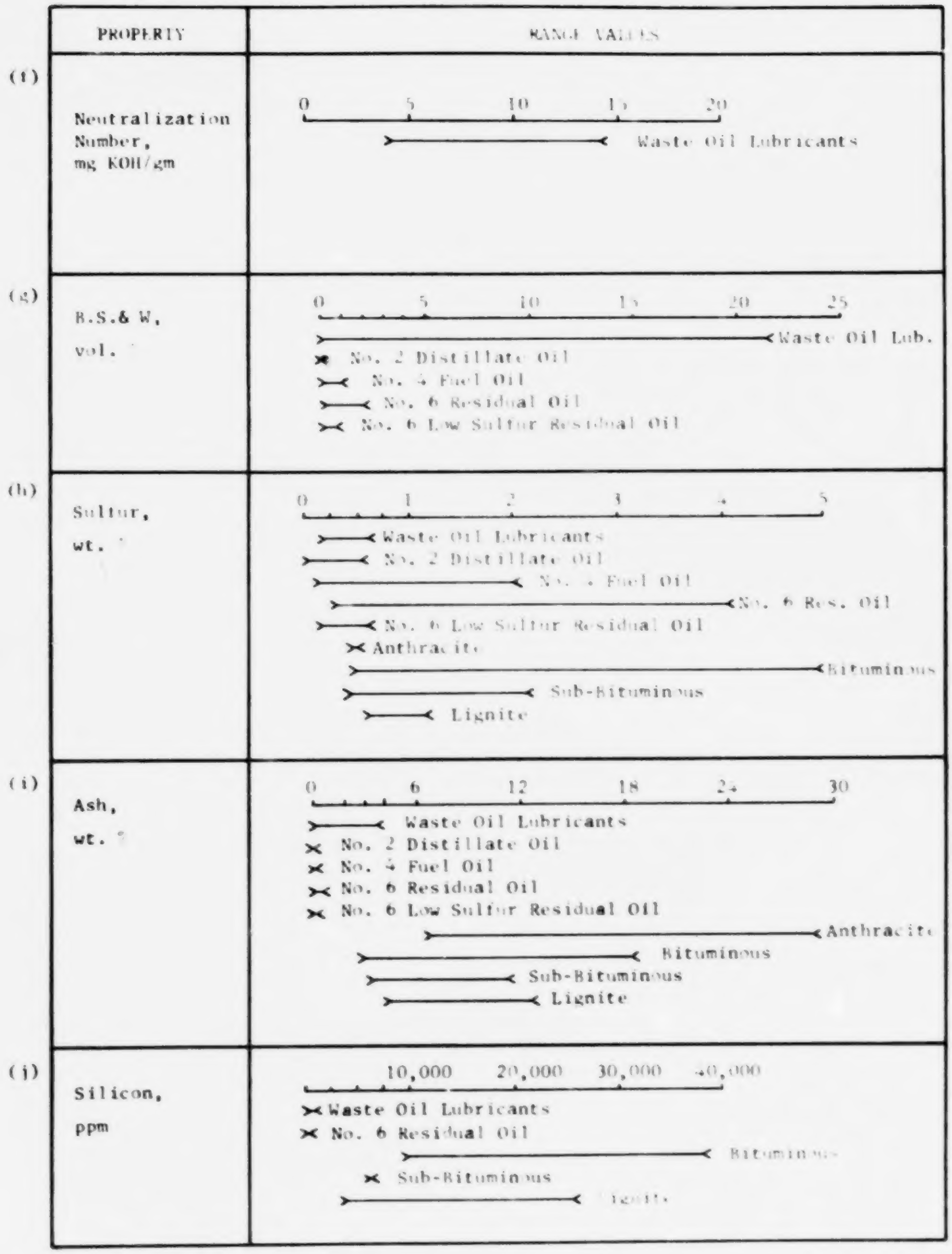

Figure 6 (continued). Comparison of waste oil and virgin fuel property ranges

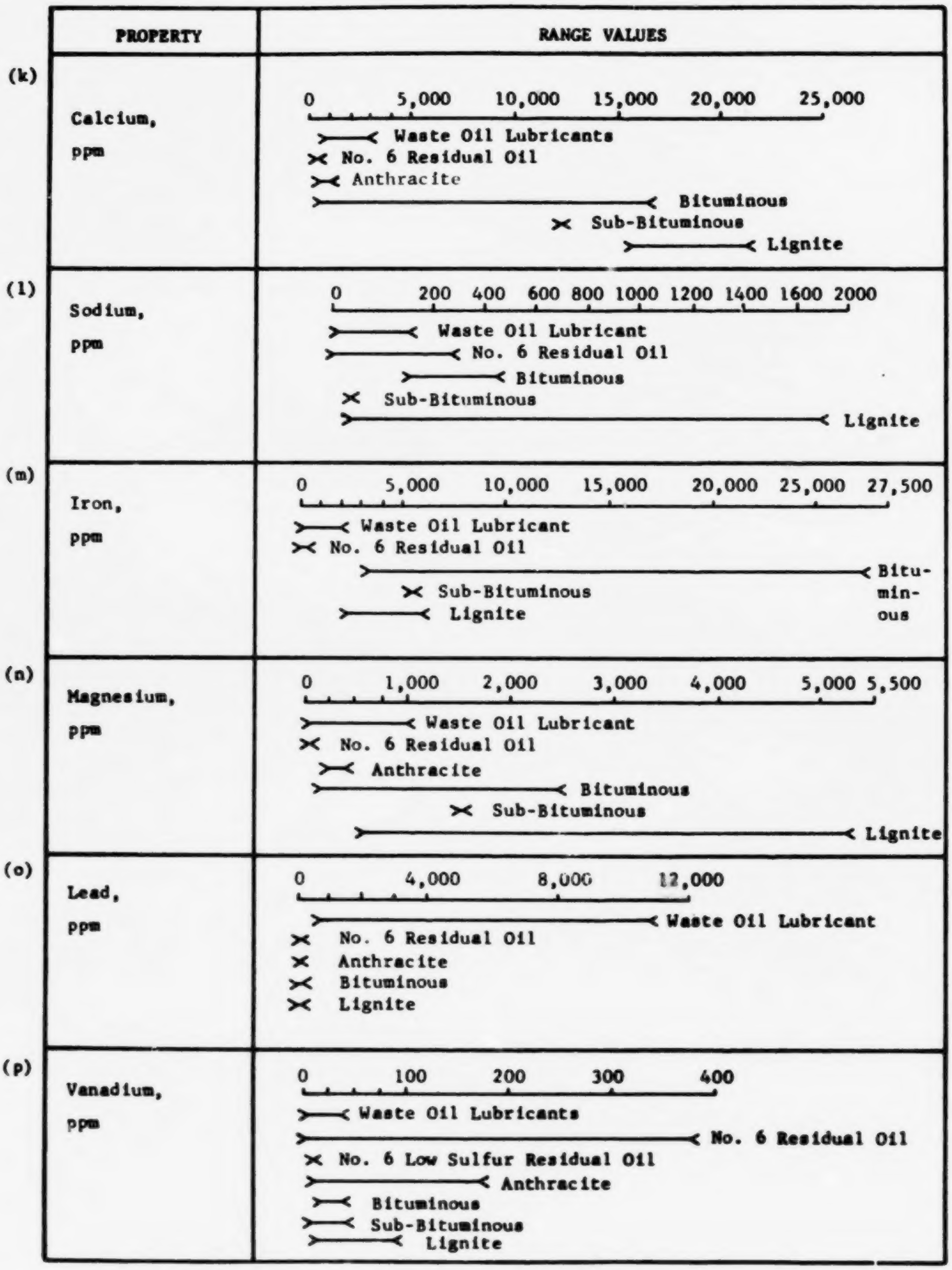

Figure 6 (continued). Comparison of waste oil and virgin fuel property ranges

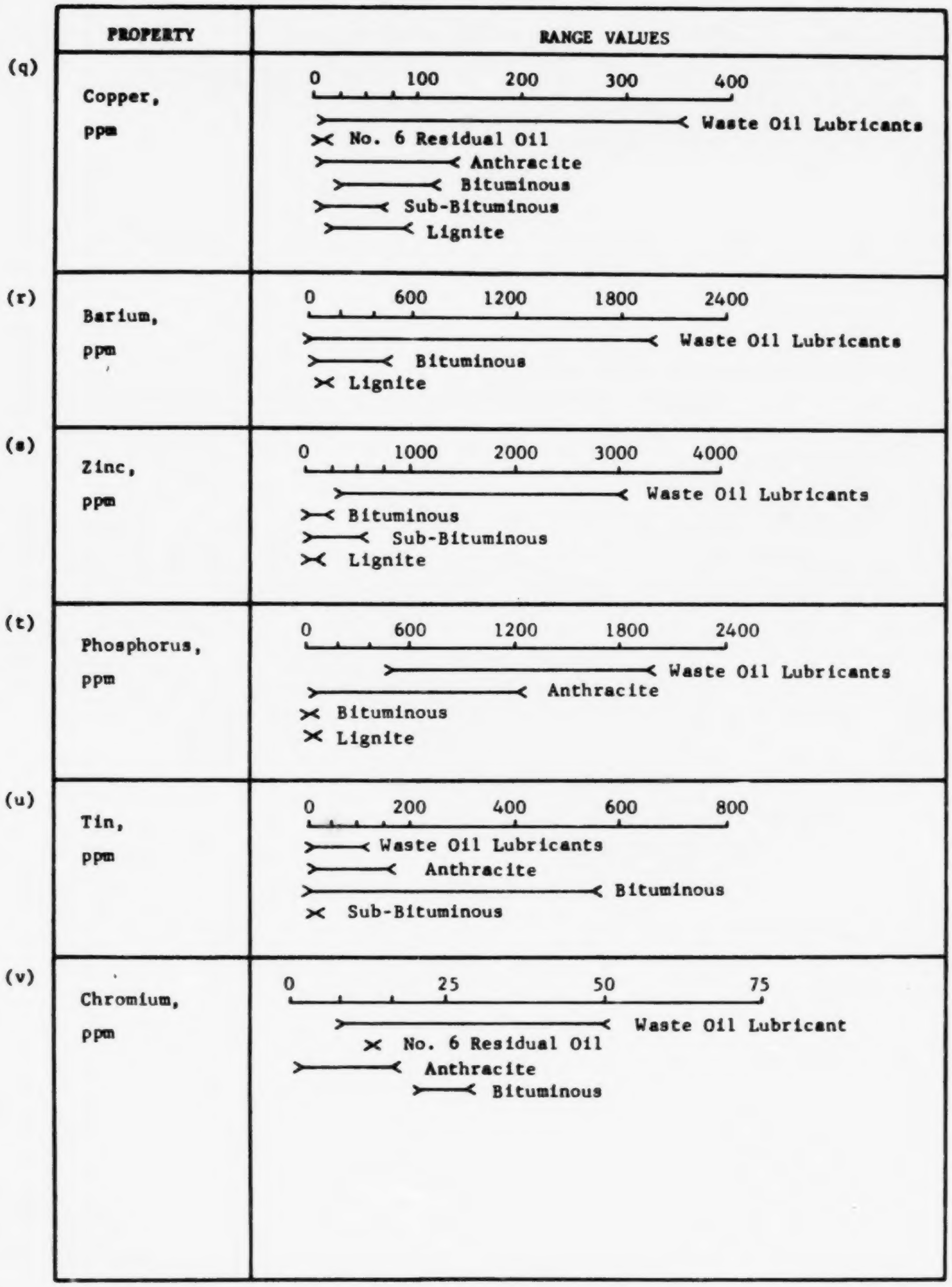

Figure 6 (continued). Comparison of waste oil and virgin fuel property ranges

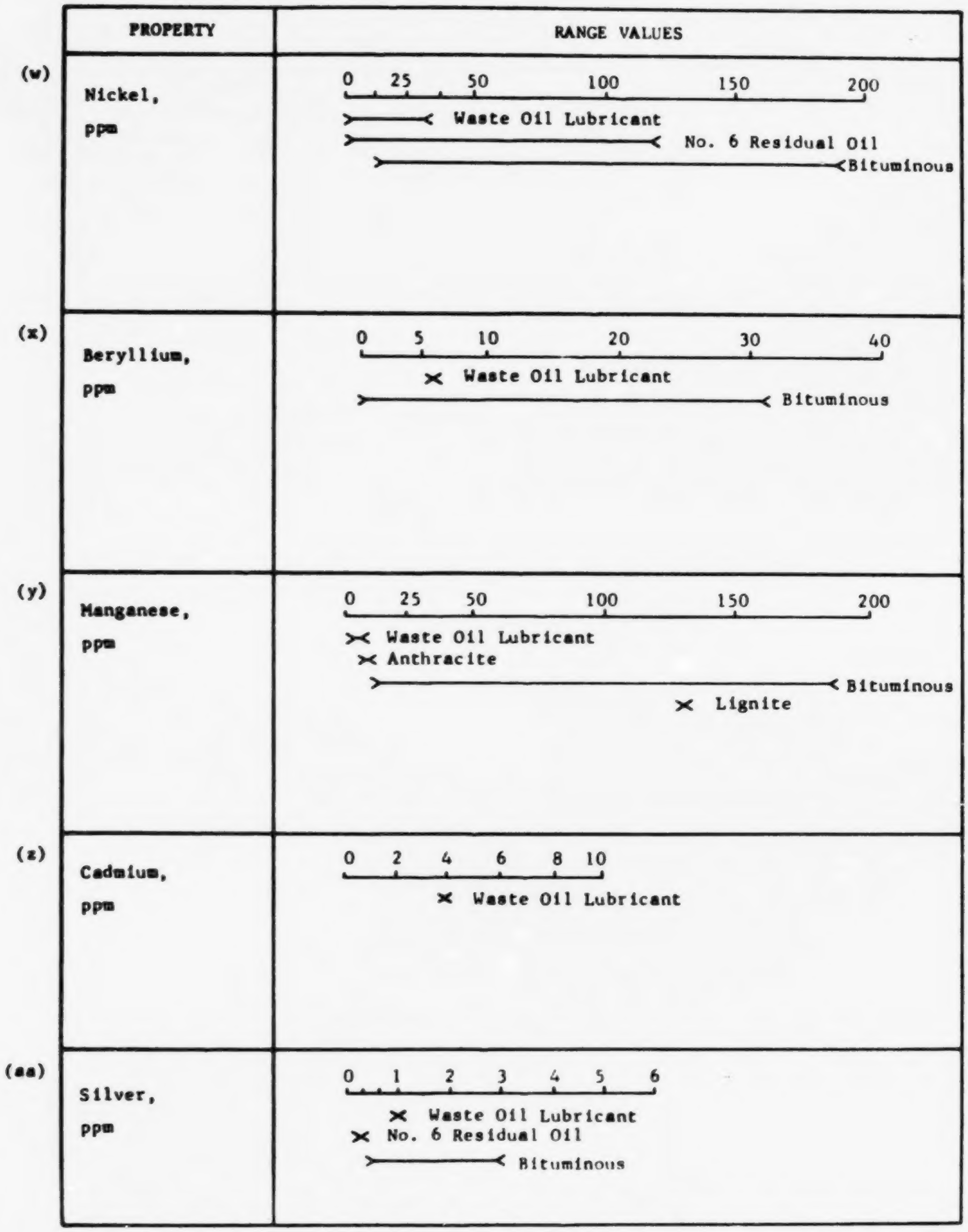

Figure 6 (continued). Comparison of waste oil and virgin fuel property ranges

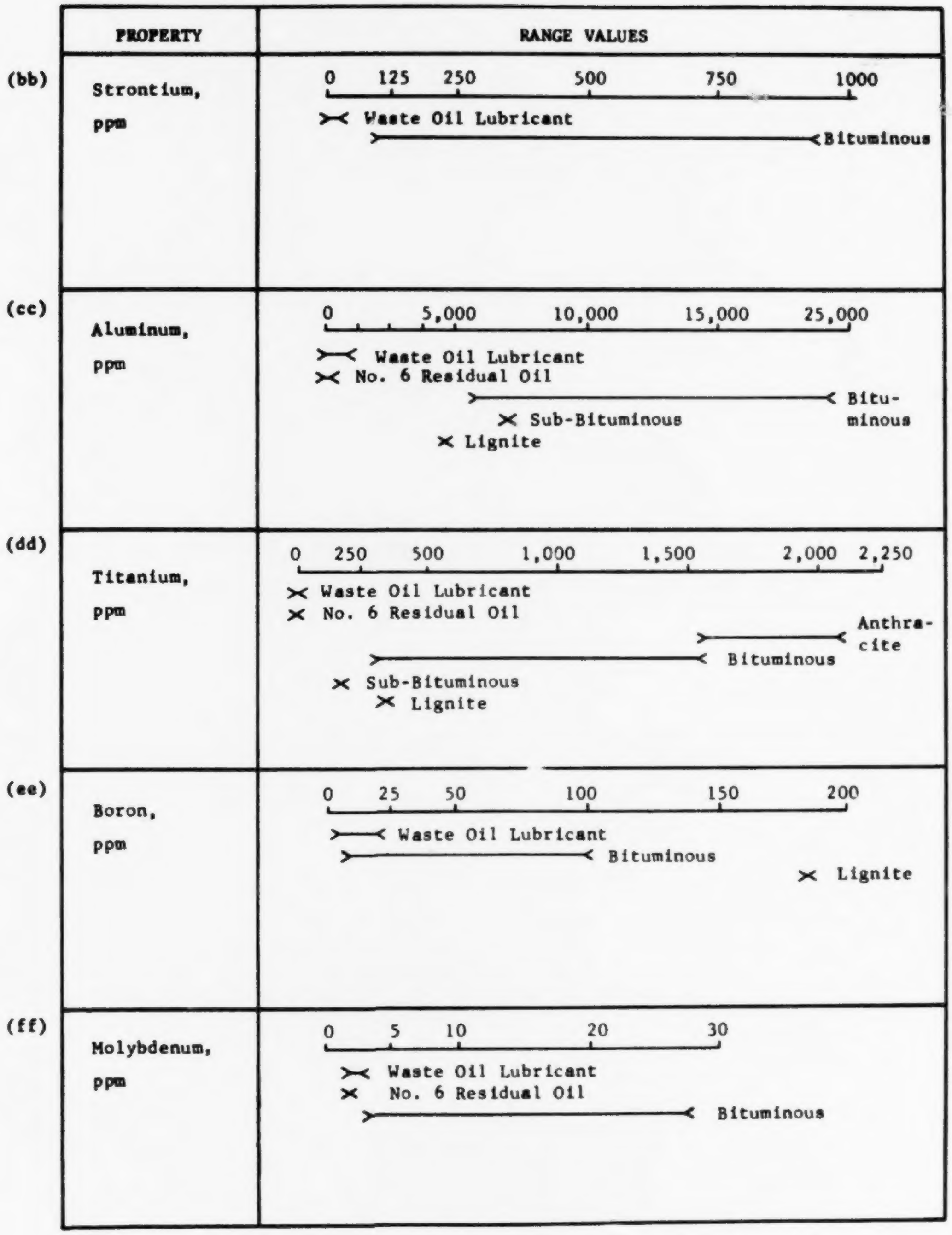

Figure 6 (continued). Comparison of waste oil and virgin fuel property ranges

VISCOSITY (CENTISTOKES)

Viscosity is a measure of a fluid's internal resistance to flow. It expresses the proportionality between the shear stress and shear rate in a flowing fluid. The viscosity of oil decreases with increasing temperature. Many crankcase lubricants contain viscosity index improvers which inhibit this reduction of viscosity with increasing temperature. As shown by Figure 6(b), the viscosity of waste oil lubricants ranges from 17.3 to 180.6 CS. This range lies within the lower end of the viscosity ranges for residual (7.0-750 CS) and low sulfur residual (1.8-362.0 CS) fuel oils. Number 2 (1.8-4.1 CS) and Number 4 (2.6-64.6) oils are generally less viscous than waste oil lubricants.

POUR POINT (°F)

Pour point can be described as the lowest temperature at which oil flows. Crankcase lubricants often contain pour depressants which lower the pour points of these oils. The pour point range of waste oil lubricants [(-40) → (-30) °F] is lower than those of number 4 [(-25) → 75 °F], number 6 [(-10) →(95)°F] and low sulfur number 6 (5 - 115 °F) fuel oils. The pour point of distillate oils [(-50) → 25 °F] is either comparable to or greater than that of waste oil lubricants.

FLASH POINT (°F)

Flash point will be defined as the lowest temperature at which the vapor above an oil will ignite. The flash point range for waste oil lubricants lies between 175 and 415 °F. As shown by Figure 6(d), the lower end of this range is comparable to the upper end of the ranges for distillate (126-204 °F), number 4 (142-240 °F), residual (150-270 °F), and low sulfur residual (150-370 °F) fuel oils.

HEATING VALUE (BTU/lb)

Due to its high water content, the heating value range of waste oil lubricants (13,571-19,300 BTU/lb) is comparable to or slightly lower than the heating value ranges for distillate (18,145-19,895 BTU/lb), number 4 (18,280-19,400 BTU/lb), residual (17,410-20,480 BTU/lb), and low sulfur residual (18,720-19,700 BTU/lb) fuel oils. With respect to coal, the heating value of waste oil lubricants is generally comparable to or greater than that of anthracite (9,620-17,500 BTU/lb), bituminous (9,171-15,800 BTU/lb), sub-bituminous (8,300-11,500 BTU/lb), and lignite (6,300-14,300 BTU/lb) coals.

NEUTRALIZATION NUMBER (mg KOH/g)

Neutralization number is a measure of the acidity or basicity of an oil. This number represents either milligrams of 0.1 N potassium hydroxide (KOH) required to neutralize one gram of acidic oil or the milligrams of 0.1 N hydrochloric acid (HCl), expressed as milligrams

KOH, required to neutralize one gram of basic oil. The neutralization number for waste oil lubricants ranges from 4.0 to 14.3 mg KOH/gram.

BOTTOM SEDIMENT AND WATER (VOLUME %)

Bottom sediment and water (BS&W) is material which is insoluble in oil and can usually be removed by adding a solvent and centrifuging (ASTM D96). As outlined previously, waste oil lubricants derive their BS&W content from "Piston Blowby" and engine deposits as well as other materials added to the oil during storage and handling. Detergent additives present in many waste oils keep much of this sediment and water emulsified.

Figure 6(g) shows that the BS&W content of waste oils can be as high as 22.0 volume %, whereas the virgin fuels are generally comprised of less than 2.0 volume % BS&W.

SULFUR CONTENT (WEIGHT %)

The sulfur content of fuels occurs naturally and is sometimes reduced by desulfurization as is often the case for low sulfur residual fuel oils. As shown by Figure 6(h), the sulfur content of waste oil lubricants (0.21-0.65 wt. %) is generally comparable to or slightly greater than the ranges for distillate (0.02-0.59 wt. %), and low sulfur residual (0.15-0.60 wt. %) fuel oils. The waste oil lubricant range is enclosed within the lower end of both the ranges for number 4 (0.2-2.0 wt. %) and residual (0.3-4.0 wt. %) fuel oils. For the most part, the sulfur content of waste oil is lower than that of anthracite (0.5 wt. %), bituminous (0.5-5.0 wt. %), sub-bituminous (0.4-2.1 wt. %), and lignite (0.7-1.1 wt. %) coals.

ASH CONTENT (WEIGHT %)

Ash content is a measure of the residue remaining after a fuel has undergone complete combustion and when further heating in the presence of oxygen produces no further change in weight. Waste oil ash constituents can be derived from "piston blowby" engine fretting and wear, and the presence of functional additives.

The ash content range of waste oil lubricants (0.03-3.78 wt. %) is higher than the ranges for distillate (0.002-0.005 wt. %), and low sulfur residual (0.001-0.10 wt. %). Number 4 (0-0.1 wt. %) and number 6 (0.00-0.50 wt. %) fuel oils have ash contents that are sometimes comparable to but generally lower than the ash content range for waste oils. All four grades of coal; anthracite (6.9-28.3 wt. %), bituminous (3.0-18.0 wt. %), sub-bituminous (3.8-11.2 wt. %), and lignite (5.0-12.8 wt. %) have higher ash contents than do waste oil lubricants.

SILICON CONTENT (ppm AS THE ELEMENT)

Silicon compounds in waste oils usually occur as anti-foamant additives whose function is to prevent excessive oxidation. The silicon content of waste oil lubricants (10-875 ppm) is sometimes comparable to but generally greater than that of residual (8.2-164.0 ppm) fuel oil. Bituminous (9,818-38,500 ppm), sub-bituminous (7,390 ppm), and lignite (4,180-25,000 ppm) coals all have silicon contents larger than those of waste oil lubricants.

CALCIUM CONTENT (ppm AS THE ELEMENT)

Waste oil lubricants contain calcium in concentrations ranging from 700 to 3,000 ppm. As illustrated by Figure 6 (k), this value range runs considerably higher than the range for residual oils (0.7-95.0 ppm). The calcium concentration range of waste oil lubricants lie within the lower end of the range for bituminous coals (527-15,009 ppm). Sub-bituminous (12,300 ppm), and lignite (16,100-21,300 ppm) coals have calcium contents above and anthracite (252-503 ppm) coal has calcium contents below those of waste oil lubricants.

SODIUM CONTENT (ppm AS THE ELEMENT)

The sodium concentration range for waste oil lubricants varies from 16 to 300 ppm. This range is comparable to and lies within the range for residual oils (1-480 ppm). As shown by Figure 6 (l), the sodium concentration ranges for bituminous (293-645 ppm), sub-bituminous (98 ppm), and lignite (75-1,921 ppm) coals are within or above the sodium concentration range for waste oil lubricants.

IRON CONTENT (ppm AS THE ELEMENT)

The iron content of waste oil lubricants occurs as a result of engine wear and ranges from 50 to 2,000 ppm. This range is subsequently higher than for residual oil (10.5-230 ppm). The values for bituminous (3,230-23,103 ppm), sub-bituminous (5,080 ppm), and lignite (2,100-5,910 ppm) are all significantly higher than the range for waste oil lubricants.

MAGNESIUM CONTENT (ppm AS THE ELEMENT)

The magnesium concentration in waste oil lubricants ranges from 10 to 1,108 ppm as shown in Figure 6 (n). This range is significantly higher than the range for residual fuel oil (0.4-27.9 ppm). The magnesium concentrations for most coals range within or above the values for waste oils as follows: (435-1,590 ppm) for bituminous, (1,590 ppm) for sub-bituminous, and (603-4, 590 ppm) for lignite. The only exception. anthracite coal (425-955 ppm), has a range which lies within that of waste oil.

LEAD CONTENT (ppm AS THE ELEMENT)

The lead concentration in waste oil is derived from "piston blowby" and ranges from 800 to 11,200 ppm. As illustrated by Figure 6 (o), this value range is considerably larger than the values for residual oils (1.7-4.1 ppm), as well as anthracite (1.8-17.6 ppm), bituminous (4.5-137 ppm), and lignite (8.9-89 ppm) coals.

VANADIUM CONTENT (ppm AS THE ELEMENT)

Waste oil lubricants have vanadium concentrations from 3 to 39 ppm. This range is comparable to or less than that of residual (1-380 ppm) and encompasses that of low sulfur residual (15 ppm) fuel oils. The ranges for anthracite (17.6-176 ppm), bituminous (19-41 ppm), and lignite (8.9-89 ppm) coals are within or greater than the range for waste oil. The range for sub-bituminous coal (0.8-44 ppm) encompasses the range of vanadium content values for waste oil lubricants.

COPPER CONTENT (ppm AS THE ELEMENT)

As illustrated in Figure 6 (q), the copper content of waste oil lubricants range from 5 to 348 ppm. The value found for residual oils (0.5 ppm) is below this range. The ranges for anthracite (1.8-123 ppm) and sub-bituminous (1.5-53 ppm) coals are within or below the waste oil range while the ranges for bituminous (23-105 ppm) and lignite (8.9-89 ppm) are completely within the waste oil range.

BARIUM CONTENT (ppm AS THE ELEMENT)

Barium compounds in waste oil lubricants usually occur as detergent additives that function as sludge dispersants and water emulsifiers. The barium concentration in waste oil lubricants was found to range from 10 to 2,000 ppm. The barium concentration ranges for bituminous (53-462 ppm) and lignite (132-134) coals lie within the range for waste oil lubricants.

ZINC CONTENT (ppm AS THE ELEMENT)

Zinc compounds occur in waste oil as detergents and metal deactivating antioxidants. As illustrated by Figure 6 (s), the zinc concentration in waste oil ranges from 300 to 3,000 ppm. This range value is greater than the ranges for bituminous (45-200 ppm) and lignite (8.9-35.8 ppm) coals while it overlaps that of sub-bituminous (< 525 ppm) coal.

PHOSPHORUS CONTENT (ppm AS THE ELEMENT)

Phosphorus compounds in waste oil function as antioxidants, antiwear agents, rust preventors, metal deactivators, and detergents. The phosphorus content of waste oil ranges from 500 to 2,000 ppm. This value range is greater than the ranges for bituminous (20-40 ppm) and lignite (50 ppm) coals while it is greater than or equal to the range for anthracite (70-1,220 ppm) coals.

TIN CONTENT (ppm AS THE ELEMENT)

The tin content of waste oil ranges from 5-112 ppm. This range is higher than the tin content of sub-bituminous coal (1.5-7.5 ppm) but lower than the range of tin contents in bituminous (0.4-550 ppm) and anthracite coals (17.6-158 ppm).

CHROMIUM CONTENT (ppm AS THE ELEMENT)

As illustrated by Figure 6(v), the chromium content of waste oil lubricants ranges from 8 to 50 ppm. This range is comparable to or greater than the range for anthracite coal (1.8-17.6 ppm) while it encompasses residual oil (13.7 ppm) and bituminous coal (20-28 ppm) ranges.

NICKEL CONTENT (ppm AS THE ELEMENT)

The nickel content of waste oil lies between the values of 3 and 30 ppm. This range lies on the lower end of the range for residual oils (3-118 ppm) and is less than or equal to the nickel in bituminous coals (13-189 ppm).

BERYLLIUM CONTENT (ppm AS THE ELEMENT)

The beryllium content of waste oil lubricants lies around the value of 6 ppm. As shown by Figure 6(x), this value is within the lower end of the bituminous coal (0.1-31 ppm) beryllium content range.

MANGANESE CONTENT (ppm AS THE ELEMENT)

The manganese content of waste oil ranges from 5 to 10 ppm. This range is either less than or within the range for anthracite coal (8.2-10.9 ppm. As shown by Figure 6(y), the content values for both bituminous (13-189 ppm) and lignite (13 ppm) coals are above the waste oil range values.

CADMIUM CONTENT (ppm AS THE ELEMENT)

The cadmium content of waste oil lubricants was found to be 4 ppm.

SILVER CONTENT (ppm AS THE ELEMENT)

The silver content of waste oil lubricants lies around a value of 1 ppm. As shown by Figure 6 (aa), this value is greater than that of residual oil (0.3 ppm) while it lies within the silver content range of bituminous coal (0.5-2.9 ppm).

STRONTIUM CONTENT (ppm AS THE ELEMENT)

Waste oil lubricants were found to have a strontium content ranging from 10 to 30 ppm. This range is below that of bituminous coal (95-935 ppm).

ALUMINUM CONTENT (ppm AS THE ELEMENT)

As shown by Figure 6 (cc), the aluminum content range of waste oil lubricants (10-800 ppm) is comparable to or greater than the range for residual oil (0.5-219 ppm). Bituminous (5,557-19,448 ppm), sub-bituminous (6,935 ppm), and lignite (3,468-9,146 ppm) coals all have aluminum content ranges greater than that of waste oils.

TITANIUM CONTENT (ppm AS THE ELEMENT)

The titanium content of waste oil lubricants (5-30 ppm) encompasses the value found for residual oils (5.5 ppm). As shown by Figure 6 (dd), anthracite (1,583-2,110 ppm), bituminous (315-1,574 ppm), sub-bituminous (188 ppm) and lignite (102-782 ppm) all have titanium content ranges above that found for waste oil lubricants.

BORON CONTENT (ppm AS THE ELEMENT)

Boron compounds function in lubricating oils as multipurpose detergent additives. The boron content of waste oils was found to range from 3 to 20 ppm. As illustrated by Figure 6 (ee), this range lies within or below the range for bituminous coal (8.4-101 ppm). Lignite coal (185 ppm) contains considerably more boron than waste oils.

MOLYBDENUM CONTENT (ppm AS THE ELEMENT)

Molybdenum is a solid lubricant which is often added to lubricating oils. The molybdenum content of waste oils (2-3 ppm) encompasses the content value found for residual oils (2.3 ppm). As shown by Figure 6 (ff), bituminous coal has a molybdenum content range slightly higher than that of waste oil lubricants.

SECTION VI

TECHNICAL FEASIBILITY OF UNTREATED WASTE OIL AS A FUEL

The feasibility of utilizing waste oil lubricants as a virgin fuel (coal and oil) blending component is dependent upon various technical and environmental considerations. These technical factors will be assessed in this section; the environmental considerations are presented in Section VII.

The technical feasibility of utilizing waste oil as a blending component with virgin fuels is a function of: (1) any additional storage or handling considerations that might result from such a utilization, (2) the blending compatability of waste oil with the virgin fuels being considered, (3) any combustion impacts that might be created by such a utilization, and (4) any other impacts that might result from the introduction of any foreign materials into a system via waste oil utilization. The forthcoming development reviews the properties presented in the preceding section and discusses how they affect the technical feasibility of utilizing waste oil as a fuel blending component. Tables 9, 10, and 11 compliment this discussion by respectively characterizing waste oil/distillate oil, waste oil/residual oil, and waste oil/bituminous coal blends.

SPECIFIC GRAVITY

As illustrated in Tables 9 and 10, the specific gravity of well-mixed waste oil/distillate oil and waste oil/residual oil blends in concentrations as high as 25 percent does not vary appreciably from the specific gravity of the virgin fuels prior to the addition of waste oil. The combustion testing conducted at Aberdeen Proving Grounds[33] revealed that waste oil/distillate oil blends being stored for any reasonable length of time should be subjected to some form of mixing in order to prevent the formation of concentration gradients. Since a specific gravity differential also exists between waste oils and residual oils, it is reasonable to assume that this same phenomena would occur during prolonged periods of joint storage. If the combined storage of waste oil and fuel oils is to be practiced, it seems advisable to employ steam heating coils in the storage tanks. These coils, commonly used to prevent the solidification of high pour point oils, will accomplish mixing and heating through convective heat transfer. The specific gravity of water and sedimentary solids present in waste oil

Table 9. CHARACTERIZATION OF WASTE OIL/DISTILLATE OIL BLENDS[a]

Property	Value[b]					
	0% waste oil	1% waste oil	5% waste oil	10% waste oil	25% waste oil	100% waste oil
Gravity, °API a 60°F	37.8	37.7	37.1	36.4	34.4	24.0
Viscosity, Centistokes	3.0	3.0	4.0	5.0	11.0	99.0
Pour Point, °F	-12.5	-12.7	-13.6	-14.8	-18.1	-35
Flash Point, °F	165	166.3	171.5	178.0	197.5	295
Heating Value, BTU/lb.	19,020	18,994	18,891	18,762	18,374	16,436
BS&W, vol. %	0.05	0.16	0.60	1.15	2.79	11.0
Sulfur, wt. %	0.310	0.311	0.316	0.322	0.340	0.430
Ash, wt. %	0.0025	0.022	0.098	0.193	0.479	1.91

[a] The properties of these blends are assumed to be linearly related to their constituents' properties except for viscosity which was calculated using the Kendall-Monroe equation.

[b] Median values from the composite property ranges presented in Appendix E were used in order to obtain property values for blends.

Table 10. CHARACTERIZATION OF WASTE OIL/RESIDUAL OIL BLENDS[a]

Property	Value[b]					
	0% waste oil	1% waste oil	5% waste oil	10% waste oil	25% waste oil	100% waste oil
Gravity, [c]API a 60°F	13.2	13.3	13.7	14.3	15.9	24.0
Viscosity, Centistokes	379	365	345	338	288	99.0
Pour Point, °F	52.5	51.6	48.1	43.8	30.6	-35
Flash Point, °F	210	211	214	219	231	295
Heating Values, BTU/lb.	18,945	18,920	18,820	18,694	18,318	16,436
BS&W, vol.%	1.00	1.10	1.50	2.00	3.50	11.0
Sulfur, wt.%	2.15	2.13	2.06	1.98	1.72	0.43
Ash, wt.%	0.25	0.27	0.33	0.42	0.67	1.91
Silicon, ppm	86.1	89.7	104	122	175	443
Calcium, ppm	47.9	65.9	138.0	228	498	1,850
Sodium, ppm	240.5	239.7	236	232	220	158.0
Iron, ppm	120.3	129	166	211	346	1,025
Magnesium, ppm	14.2	19.6	41.4	68.7	150.4	559
Lead, ppm	2.9	63	303	603	1,502	6,000
Vanadium, ppm	190.5	188.8	182	171.5	148.1	21
Copper, ppm	0.5	2.3	9.3	18.2	44.6	177
Chromium, ppm	13.7	13.9	14.5	15.2	17.5	29
Nickel, ppm	60.5	60.1	58.3	56.1	49.5	16.5

Table 10. (continued) CHARACTERIZATION OF WASTE OIL/RESIDUAL OIL BLENDS[a]

Property	Value[b]					
	0% waste oil	1% waste oil	5% waste oil	10% waste oil	25% waste oil	100% waste oil
Silver, ppm	0.3	.31	.34	.37	.48	1
Aluminum, ppm	109.8	113	125	139	184	405
Titanium	5.5	5.6	6.1	6.7	8.5	17.5
Molybdenum, ppm	2.3	2.30	2.31	2.32	2.35	2.5

[a] The properties of these blends are assumed to be linearly related to their constituents' properties except for viscosity which was calculated using the Kendall-Monroe equation.

[b] Median values from the composite property ranges presented in Appendix E were used in order to obtain property values for blends.

Table 11. CHARACTERIZATION OF WASTE OIL/BITUMINOUS COAL BLENDS[a]

Property	Value[b]					
	0% waste oil	1% waste oil	5% waste oil	10% waste oil	25% waste oil	100% waste oil
Heating Value, BTU/lb.	12,486	12,526	12,684	12,881	13,474	16,436
Sulfur, wt.%	2.75	2.73	2.63	2.52	2.17	0.43
Ash, wt.%	10.5	10.4	10.1	9.64	8.35	1.91
Silicon, ppm	26,650	26,388	25,340	24,029	20,098	443
Calcium, ppm	7,768	7,709	7,472	7,176	6,289	1,850
Sodium, ppm	469	466	453	438	391	158.0
Iron, ppm	14,467	14,333	13,795	13,123	11,106	1,025
Magnesium, ppm	1,362	1,354	1,322	1,282	1,161	559
Lead, ppm	78.5	138	375	671	1,559	6,000
Vanadium, ppm	30	29.9	29.6	29.1	27.8	21
Copper, ppm	64	65.1	69.7	75.3	92.3	177
Barium, ppm	258	265	295	333	445	1,005
Zinc, ppm	123	138	199	276	505	1,650
Phosphorus, ppm	30	42	91	152	335	1,250
Tin, ppm	225.2	223.5	216.9	208.5	183.5	58.5
Chromium, ppm	24	24.1	24.3	24.5	25.3	29
Nickel, ppm	101	100	97	93	80	16.5
Beryllium, ppm	15.6	15.5	15.1	14.6	13.2	6

Table 11. (continued) CHARACTERIZATION OF WASTE OIL/BITUMINOUS COAL BLENDS[a]

Property	Value[b]					
	0% waste oil	1% waste oil	5% waste oil	10% waste oil	25% waste oil	100% waste oil
Manganese, ppm	101	100	96	92	78	7.5
Silver, ppm	1.7	1.69	1.67	1.63	1.53	1
Strontium, ppm	515	510	490	466	391	20
Aluminum, ppm	12,503	12,382	11,898	11,293	9,479	405
Titanium, ppm	945	936	899	852	713	17.5
Boron, ppm	54.7	54.3	52.5	50.4	3.9	11.5
Molybdenum, ppm	15.6	15.5	14.9	14.3	12.3	2.5

[a] The properties of these blends are assumed to be linearly related to their constituents' properties.

[b] Median values from the composite property ranges presented in Appendix E were used in order to obtain property values for blends.

lubricants is greater than that of the three oils being considered. This means that allowed sufficient time, free BS&W would settle to the bottom of a storage tank. Emulsifiers which are present in most waste oils inhibit the settling of these undesirable materials while heating these oils enhances settling via the reduction of oil viscosity. Some type of drain valve or suction line should be present in the bottom of combined storage tanks in order to facilitate the removal of BS&W before these materials reach the level of oil drawoff.

VISCOSITY

The viscosity of a 10-percent waste oil/distillate oil blend is over three times that of distillate oil while the viscosity of 10 percent waste oil/residual oil blends is only slightly less than the viscosity of residual oil. GCA noted from both its field study and questionnaires that possible pumping restrictions due to waste oil viscosity was an area of concern.

Classically, two general categories of pumps are employed for fuel oil transport; centrifugal and positive displacement pumps. Centrifugal pumps are recommended for fuel oils with viscosities below 450 centistokes.[46] Above this viscosity, the pumps run inefficiently and it is likely that cavitation may occur.[47] Centrifugal pumps are almost always used for distillate oils. As far as viscosity is concerned, these pumps seem quite suitable for waste oil/distillate oil blends. Positive displacement pumps are recommended for fuel oils with viscosities above 450 centistokes. These pumps are quite capable of operating below this viscosity with the incurrance of some efficiency losses. Positive displacement pumps are commonly employed for residual oils and in terms of viscosity, could also be employed for waste oil/residual oil blends.[48]

POUR POINT

As illustrated in Tables 9 and 10 respectively, the pour points of 10 percent waste oil/distillate oil and waste oil/residual oil blends are slightly less than the pour points of the virgin fuel oils prior to the addition of waste oil. As a lubricant, waste oils contain pour point depressants in order to prevent their solidification at cold temperatures. On the other hand, residual oils, especially those with low sulfur content, have relatively high pour points which require that they be heated in order to keep them fluid. By blending these oils with waste oils, heating requirements and solidification problems could be lessened. The linear relationship or pour point (and flash point) assumed in the tables was chosen for convenience of calculation and is not a rigorous assumption. Some variation from the values depicted will be noted in PRACTICE.

FLASH POINT

Tables 9 and 10 show that 100 percent waste oil has a higher median flash point than either distillate or residual oils. Consequently, the use of waste oil/virgin fuel oil blends would not require any safety measures other than those normally observed during virgin fuel oil use. In a few questionnaire responses, some mention was made of the potential danger of spontaneous combustion of waste oil in coal pulverizers and in hot air feeders. Through GCA'S field research it has been shown that when blending pulverized coal, waste oil should be introduced in the furnace by a separate burner system rather than blending with coal prior to pulverization.[31] This utilization technique reduces maintenance problems as well as safety hazards.

HEATING VALUE

The heating value of waste oil/distillate oil, waste oil/residual oil, and waste oil/bituminous coal blends in concentrations as high as 25 percent does not greatly differ from the heating values of the virgin fuels prior to their blending with waste oil lubricants. The heating value of untreated waste oils fluctuate due to their relatively high water content. The variability of waste oils' heat content was of concern to Portland cement manufacturers since their process requires constant heat in order to produce a high quality product.[49]

BS&W

The sediment and water content of both waste oil/distillate and waste oil/residual oil blends is noticeably greater than that of the virgin fuel oils prior to the addition of waste oil. This difference is appreciable at even low blending ratios, especially for distillate fuel oils.

When storing waste oil which is reasonably high in BS&W, a fraction of this material will usually settle to the bottom of the fuel storage tank. Eventually the level of these settled materials will reach the point of fuel drawoff.[31] Dispersant emulsifiers have been successfully used in storage tanks with waste oil/residual oil blends to prevent the water and solids from settling.[52,54]

Increased strainer plugging is a problem that has been experienced during the use of waste oils.[31] Through field research, GCA has noted that this is an area of concern to the many potential users of waste oil.[34]

Due to the water in waste oils, freezing of unheated fuel lines is a problem that has sometimes been encountered during cold weather.[31] As in the case of strainer fouling, the questionnaires also revealed concern by potential users with this problem area.[34]

The sedimentary material in waste oil is characteristically an abrasive grit. This erosive sludge does damage to the seals in positive displacement pumps.[31] Centrifugal pumps have, however, been successfully employed to transport waste oil.[52] This is due to the fact that positive displacement pumps generally have closer clearances than centrifugal pumps and are therefore more susceptible to erosion. On the other hand, given the same operating conditions, centrifugal pumps often operate less efficiently than positive displacement pumps and subsequently have higher power requirements.[56] In terms of waste oil use with coal, GCA's questionnaire survey revealed concern by potential users over the erosion of coal feeder belts due to the BS&W in waste oil.[34]

Erosion of the nozzle tips in burners has been experienced due to the abrasive materials in waste oil.[31] This problem has been avoided by employing wide orifice nozzles. For this particular case, steam was successfully used to atomize the waste oil/residual oil blends. It was felt that steam is better than air for breaking up sludge deposits.[52] Fear of increased maintenance and the corresponding costs as a result of burner erosion was frequently mentioned by potential waste oil users.[34]

Burner flameout due to the high water content in waste oil has been experienced during use. Flame sustaining torches have been employed to prevent this problem. As well as causing flameout, the water contained in waste oil causes its heating value to fluctuate. Potential users who require a constant heat source were very concerned about this inconsistency.[54,55]

For many potential applications, the BS&W in untreated waste oil blends could create problems. Two options that would reduce these problems are (1) modify the system and (2) reduce the BS&W content of the oil via pretreatment.

Sulfur

The sulfur content of waste oil/distillate oil blends does not vary appreciably from 0 to 25 percent. Waste oil/residual oil and waste oil/bituminous coal blends decrease in sulfur content with increasing blending ratio. Above a blending ratio of 10 percent, the decrease is worth noting, especially when the technical impact of sulfur is considered. As well as polluting the air, the sulfur contained in fuels can cause corrosion. In a furnace, approximately 95 percent of the sulfur contained in the fuel being combusted is oxidized to become sulfur dioxide (SO_2), while the balance becomes sulfur trioxide (SO_3). This SO_3 combines with water vapor in the flue gas to form a corrosive sulfuric acid (H_2SO_4) vapor. The acid dew point is the temperature at which this acid vapor condenses to become a mist. This sulfuric acid mist can then come into contact with internal boiler or control equipment surfaces and cause corrosion. Use of waste oil in place of virgin fuels would decrease the overall sulfur content of the fuel blend and help to alleviate these sulfur-related problems.

Ash

The ash content of waste oil/distillate oil and waste oil/residual oil blends increases with increasing blend ratios while the ash content of waste oil/bituminous coal blends decrease with increasing blend ratios. At ratios of 5 percent for waste oil/distillate oil and 10 percent for waste oil/residual oil and waste oil/bituminous coal blends, these changes are worth noting, especially since ash in fuels can be responsible for notable technical impacts.

Even though the individual ash constituents in distillate, Number 4 and low sulfur residual oils are not reported, it may be reasonably assumed that most of these constituents are present in considerably lower concentrations than are found in residual and waste oils. This assumption is supported by a comparison of the total ash content values of these fuels.

Part of the sediment in waste oils is comprised of ash-forming material. This ash is a major contributor to waste oils abrasiveness and is partially responsible for the previously discussed maintenance problems. Upon combustion, ash constituents become oxides that may either remain within the boiler and stack or be emitted to the atmosphere. Some of this ash may form deposits of slag on the furnace walls (slagging), and a portion of the ash that is carried from the furnace by flue gases may form deposits on the tubular heat transfer surfaces (fouling). Under some conditions, these deposits may lead to inefficient heat transfer as well as corrosion. Sootblowing, water washing and manual cleaning are the three most commonly employed ash removal techniques.[36]

It has been reported that in indirect heating, steam generating furnaces firing waste oil as a replacement fuel for coal, there was no increase in deposits or need for more frequent cleaning.[31] There has, however, been considerable concern shown by potential users over the possibility of increased ash deposition and corrosion in boilers when using waste oil in place of or blended with fuel oils.[32,51]

In direct heating furnaces, the flame and hot flue gas directly contact the mass being heated; therefore, ash deposition on heat transfer surfaces is not a problem. Since the mass being heated comes into intimate contact with fuel ash, potential product contamination must be considered.

Silicon

As shown in Tables 10 and 11 respectively, the silicon content of waste oil/residual oil blends increases slightly with increasing blend ratios while the content of waste oil/bituminous coal blends decreases appreciably with increasing blend ratios. Silicon oxide (SiO_2) is a very common acid coal ash constituent.

The manufacture of Portland cement employs direct-fired drying kilns. Since Portland cement inherently contains silicon, product contamination is not a problem.[56] The technical impact created by silicon from blend ratios of 5 percent or less in residual oil or bituminous coal appears to be minimal.

Calcium

The calcium content of waste oil/residual oil blends increases while the content of waste oil/bituminous coal decreases with increasing blend ratios.* Calcium oxide (CaO) is a common basic coal ash constituent. When coal contains a large amount of calcium, calcium sulfate ($CaSO_4$) will be created upon combustion. This substance forms very hard deposits that are difficult to remove by water washing. On the other hand, calcium compounds prevent oil ash corrosion by forming high melting point complexes.[36]

One reference[57] indicates that based on 100 percent waste oil combustion, 25 percent of the calcium oxidized remains in indirect heating boilers while the balance is emitted to the atmosphere. As previously mentioned, the manufacture of Portland cement employs direct fired drying kilns. Since calcium makes up roughly 66 percent of the cement, the calcium in waste oil would be of no consequence.[56]

The technical impact created by calcium from blend ratios of 5 percent or less appears to be minimal. For bituminous coal, the effect of waste oil on calcium content could actually be beneficial.

Sodium

As shown by Tables 10 and 11 respectively, the sodium content of both waste oil/residual oil and waste oil/bituminous coal blends decreases slightly with increasing blend ratios.+ Sodium oxide (Na_2O) is a basic coal ash constituent. This constituent increases coal fly ash strength and therefore makes deposits more difficult to remove by sootblowing. Sodium-iron and sodium-aluminum complexes, which are also coal ash constituents, appear in the molten state and cause the corrosion of boiler heat exchange surfaces. The sodium in fuel oil combines with vanadium after combustion to form sodium vanadates. These sodium vanadium complexes also appear in the molten state and cause the corrosion of heat exchange surfaces by a fluxing action.[36] Methods for water washing residual oil to remove sodium are presently being employed.[37]

For both bituminous coal and residual oil blends, the effect of waste oil on the sodium content appears to be minimal in blends of 5 percent or less.

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*The results of GCA's questionnaire indicated that some potential waste oil users desired that the calcium be removed from waste oil prior to its use as a fuel.[34]

+The results of GCA's questionnaire indicated that some potential waste oil users desired that the sodium be removed from waste oil prior to its use as a fuel.[34]

Iron

The iron content of waste oil/residual oil blends increases with increasing blend ratios while the iron content of waste oil/bituminous coal decreases with increasing blend ratios. The results of the questionnaire again indicated that some potential users desire the removal of iron from waste oil prior to its use as a fuel.[34]

Iron oxide (Fe_2O_3) is a very common basic coal ash constituent. It has a dominating influence on the behavior of the ash in a furnace, as indicated by its effect on the ash softening temperature. In the completely oxidized form (Fe_2O_3) iron tends to raise the ash fusion temperature while in the lesser oxidized form (FeO) it tends to lower it. Iron may combine with sodium sulfates and potassium sulfates to form molten complexes that cause the corrosion of heat exchange surfaces.[36]

Since Portland cement contains iron, the use of waste oil in direct drying kilns would not cause product contamination.[56] Based on 100% boiler combustion tests, 68 percent of the iron in waste oil remains in the boiler while the balance is emitted to the atmosphere.[57]

Magnesium

As illustrated by Tables 10 and 11 respectively, the magnesium content in waste oil/residual oil blends increases with increasing blend ratios while the magnesium content in waste oil/bituminous coal blends decreases with increasing blend ratios. Magnesium oxide (MgO) is a basic coal ash constituent. It lessens coal fly ash strength and makes boiler cleaning by sootblowing easier. Magnesium in fuel oil also forms a high melting point ash and prevents corrosion. It complexes with corrosive SO_3 gas[36] and for this reason, is often used as a corrosion inhibiting additive.

For bituminous coal blends, the technical impact of magnesium in waste oil is negligible while for residual oil blends it appears to be beneficial.

Lead

The lead content of both waste oil/residual oil and waste oil/bituminous coal blends appreciably increases with increasing blend ratios. The results of GCA's questionnaires indicated that many potential users were concerned with the high lead content of waste oil and that they desired the removal of this metal prior to the use of waste oil as a fuel. Many potential users are concerned about a health hazard and increased maintenance cost due to lead deposition on heat exchange surfaces.[51,34] Conflicting observations concerning lead in waste oil and increased boiler tube deposition have been reported. When used in place of coal, deposition has remained constant[31] while when used with oil, increased deposition is reported.[57,42]

Due to high lead content of waste oil, General Portland Cement Company was reluctant about considering the use of waste oil as a fuel in their direct fired drying kilns since soluble lead oxide in concentrations as low as 0.001 percent stops cement from setting up.[56] This information was contrasted with data from Northern States Power.[32] NSP conducted tests in which they utilized a waste oil/coal blend (< 5 with waste oil) in a 50 mw boiler equipped with an electrostatic precipitator. NSP normally sells their flyash collected by their precipitator to a Portland cement company as aggregate makeup. The flyash resulting from waste oil combustion contained 230 ppm of lead (normal lead content is 30 ppm when waste oil is not fired). Solubility tests conducted by NSP indicated that only 0.1 ppm of this increased lead content in the flyash was soluble in hot water. It was therefore concluded that this additional lead content would not interfere with the acceptability of this byproduct flyash as a makeup material in cement manufacture.

In addition to the above considerations, lead in the ash may also contribute to inefficient boiler operation due to fouling of heat exchange surfaces. From 40 to 97% of the lead entering with the waste oil has been reported to remain in the boiler system, either as deposits on heat transfer surfaces or as part of bottom ash.

Vanadium

The vanadium content of both waste oil/residual oil and waste oil/bituminous coal blends decreases with increasing blend ratio. The results of GCA's questionnaires indicated that some potential waste oil users desired that the vanadium be removed from waste oil prior to use as a fuel. Many residual oils contain vanadium. Upon combustion, much of this vanadium forms vanadium pentoxide (V_2O_5) which in turn reacts with sodium compounds to form low melting point, corrosive sodium vanadate complexes. Sulfur trioxide (SO_3) is formed as a result of this reaction. This sulfurous gas will combine with water vapor to form sulfuric acid gas which will condense corrosive sulfuric acid mist if the temperature is low enough. Magnesium compounds are often employed to inhibit the corrosive mechanisms of vanadium.[37,58]

In terms of technical impacts, the effect of waste oil on the vanadium content of residual oil and bituminous coal blends will usually be beneficial.

Copper

The copper content for a 5 percent waste oil/residual oil blend increases twentyfold over what the content is in the fuel prior to the addition of waste oil. For waste oil/bituminous coal blends, the copper content does not change greatly with increasing blend ratios up to 5 percent. No technical impacts associated with increased copper content of the fuel was determined.

Barium

As shown by Table 11, the barium content of waste oil/bituminous coal blends increases slightly with increasing blend ratios. The difference between the barium content of virgin bituminous coals and waste oil/bituminous coal blends up to 5 percent is small. It was noted in our questionnaire results that some potential waste oil users desired that barium be removed from waste oil prior to its use as a fuel. Barium causes deposition on boiler heat transfer surfaces.[59] Based on 100 percent waste oil combustion testing, 73 percent of the barium in waste oil remains in the boiler while the balance is emitted.[57]

The technical impacts of barium in waste oil on waste oil/virgin fuel blends is somewhat detrimental in terms of boiler efficiency as a result of deposit formation on heat transfer surfaces.

Zinc

The zinc content of waste oil/bituminous coal blends appreciably increases with increasing blend ratios. Questionnaire results again showed that some of the potential waste oil users desired that the zinc be removed from waste oil prior to use. Through GCA's primary data collection effort it was found that Portland cement manufacturers were concerned about water soluble zinc oxides in their product. This metallic oxide stops the cement from setting.[55,56] The water solubility of the zinc oxide generated upon the combustion of waste oil has not been established in this study. Based on 100 percent waste oil combustion testing, 38 percent of the zinc in waste oil remains in the boiler while the balance is emitted to the atmosphere.[57]

Phosphorus

The phosphorus content of waste oil/bituminous coal blends notably increases with increasing waste oil concentration. Again, the questionnaire results reflected a desire that this constituent be removed prior to combustion. As in the case of zinc, Portland cement manufacturers fear that this element will also inhibit cement solidification.[55] Based on combustion data, 35 percent of the phosphorus is retained in the boiler when firing 100 percent waste oil.[57]

Other Trace Elements

Regarding the other elements shown in Tables 10 and 11 but not discussed above, no information was found to indicate any direct technical impacts created by these elements during waste oil combustion. In fact waste oil contains significantly less of these materials than is present in bituminous coal.

SECTION VII

ENVIRONMENTAL IMPACTS OF UNTREATED WASTE OIL FUEL COMBUSTION

Examination of the characteristics of waste oil and its comparison to virgin fuels (Section V) indicates that the use of waste oil in place of or in conjunction with virgin fuels may create both beneficial and adverse impacts to the environment. Figure 6, for example, indicates that use of waste oil in place of residual oil would reduce such air pollution contaminants as:

- sulfur
- silicon
- sodium
- vanadium
- nickel

Waste oil is also a considerably cleaner burning fuel than coal, generating significantly less particulate emissions. Substituting waste oil for coal would also result in a sharp reduction in the emissions of the contaminants listed above as well as calcium, iron, magnesium, beryllium, manganese, silver, strontium, aluminum, titanium, boron, and molybdenum.

In this study, however, primary consideration is focused on the potentially adverse environmental impacts of waste oil combustion. Such potential impacts result from significant concentrations of waste oil contaminants (i.e., as much as 1 percent lead in waste oil), which may be emitted in part to the atmosphere with the flue gas. In addition, these contaminants would be partially deposited out as ash on wall and boiler tube surfaces in commercial, industrial and utility boilers, currently the most common waste oil fuel applications, resulting in particulate emissions during soot blowing operations, and potentially higher occupational hazards during cleaning of these boiler facilities.

Figure 6 in Section V shows that automotive waste oils contain a higher concentration of the following trace elements than are found in virgin fuels:

- magnesium*
- calcium*
- iron*
- lead

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*Waste oil contains more of this contaminant than fuel oils but significantly less than coal.

- copper
- barium
- zinc
- phosphorus
- silver*
- tin
- chromium

Tables 10 and 11 show, however, that the presence of some of these elements would not be significantly increased if small quantities of waste oil were blended in with residual oil and coal. Table 12 summarizes some of the information presented earlier in Section VI to highlight this point.

Table 12 presents the estimated trace element content of 1 and 5 wt. % blends of waste oil and virgin fuels (residual oil and coal). The trace element content of 100 percent waste oil and unblended virgin fuels are also presented for comparison. The circled numbers indicate those trace element contents in the blended fuels which differ significantly (> 100 percent) from the respective unblended virgin fuels. Since this table presents only the median values of trace element concentration, and the range of values for each element in a fuel may be wide (see Figure 6, Section V), we are assuming that a contaminant concentration difference of greater than 100 percent between the virgin fuel and the blend is a significant change.

Examination of this table indicates that blending 1 wt. % of waste oil with coal will not result in any substantial difference in trace element content when compared with unblended coal. A 5 wt. % blend of waste oil and coal does, however, have significantly higher lead concentration and, to a less degree, higher phosphorus content than the pure coal. This table also shows that several of the trace elements in waste oil residual/fuel oil blends have a significantly high concentration than for the unblended residual oil. However, in comparing these higher concentrations with the trace metal content of pure coal, these waste oil/fuel oil blends are dramatically cleaner except, again for lead and phosphorus.

Because of the widespread concern of lead as a hazardous pollutant, the remaining discussion will focus on lead emissions and resulting ground-level concentrations resulting from these emissions. The reader is referred to such references as EPA's Position on the Health Effects of Airborne Lead[60] for a discussion of the health effects of lead.

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*Waste oil contains more of this contaminant than fuel oils but significantly less than coal.

Table 12. INFLUENCE OF DILUTION OF WASTE OIL WITH VIRGIN FUELS ON TRACE ELEMENT CONTENT OF RESULTING BLEND

Fuel / Trace element	100% waste oil	Virgin fuels		Waste oil residual oil blend		Waste oil coal blend	
		100% residual oil	100% coal	1 wt % waste oil	5 wt % waste oil	1 wt % waste oil	5 wt % waste oil
Magnesium (ppm)	559	14	1,362	20	41	1,354	1,324
Calcium (ppm)	1,850	48	7,768	66	138	7,709	7,412
Iron (ppm)	1,025	120	14,467	129	166	14,333	13,745
Lead (ppm)	6,000	3	71	63	303	138	375
Copper (ppm)	177	1	64	2	9	65	70
Barium (ppm)	1,005	*	258	10	50	265	295
Zinc (ppm)	1,650	*	123	17	85	123	138
Phosphorus (ppm)	1,250	*	30	12	60	42	91
Silver (ppm)	1	0.3	1.7	0.3	0.3	1.7	1.7
Tin (ppm)	58	*	225	0.6	3.0	223	217
Chromium (ppm)	29	13.7	24	13.9	14.5	24.1	24.3

NOTE: Values presented are median values for ranges found in Figure 6.

◯ Indicates significant difference of greater than 100 percent between contaminant content in blend and that of virgin fuel.

*Unknown but assumed to be zero for the calculation of blend concentrations.

LEAD EMISSIONS FROM UNCONTROLLED SOURCES

Parameters Influencing Lead Emissions

In estimating lead emissions from a combustion source which fires waste oil, three basic pieces of information are required:

- The firing rate of waste oil (gallons/hour)
- The average lead content of the waste oil
- The ratio of lead ejected with the flue gas to the quantity entering with the oil

The firing rate of waste oil is obviously a function of the capacity and operating conditions of a particular combustion source. For example, a large 600-megawatt steam generating power plant, consumes about 30,000 gallons per hour of No. 6 residual oil. Based on waste oil supplies, it would be unreasonable to assume that such a plant could fire in excess of 5 wt. % of waste oil for extended durations. A 5 wt. % waste oil/fuel oil blend would result in a waste oil firing rate of 1500 gallons/hour for a 600-MW facility. Other proposed and currently practiced applications such as direct firing waste oil in rotary cement kilns, and as a supplementary fuel in smaller boilers generating steam for space heating and process use, may consume from a few gallons to several hundred gallons of waste oil per hour.

The lead content of automotive waste oil varies widely, ranging from about 0.1 → 1.0 percent based on the data presented in Figure 6. Waste oil, during the process of handling and storage, may be diluted with other oils and/or solvents but this would only tend to further dilute the lead content. Consequently, an estimate of 1.0 wt. % lead in waste oil is a good conservative value for estimating environmental impacts, as this will represent the worst case situation. The current trend towards low lead gasoline may even eliminate lead as a significant automotive waste oil contaminant in the future.

The estimation of the ratio of lead ejected from the combustion source with the flue gas to the quantity entering with the oil is difficult to predict as it again is very dependent on the combustion system and operating characteristics. For example, the nature and extent of soot blowing operations in a boiler will have a significant impact on lead emissions when firing waste oil. Also the size of the combustion chamber, combustion efficiency, operating temperatures, and chamber geometry will influence the quantity of ash emissions. A summary of available information on lead emissions from a variety of sources has been compiled and is presented in Table 13.

As seen from this table, the majority of data indicate that the amount of lead emitted with the flue gas during normal operation is less than or equal to 50 percent of the lead entering the system. It is important to note here that these are emissions estimates upstream of any collection or control system that may be present. Only one source,

Table 13. SUMMARY OF AVAILABLE DATA ON QUANTITIES OF LEAD EMITTED WITH FLUE GAS AS A PERCENTAGE OF LEAD ENTERING WITH WASTE OIL FUEL

Company	Description of combustion source	Type of virgin fuel	Total fuel feed rate	Percentage of waste oil in feed	Lead content of waste oil	Soot blowing	Lead emitted with flue gas during normal operation as a percentage of lead feed rate	Reference number
Mobil Oil	Steam boiler (18,000 lb steam/hr)	No. 6 fuel oil	147 gal/hr	5 wt %	1%	Yes	50%	42
Shell Oil	Steam boiler (60,000 lb steam/hr)	No. 6 fuel oil	374-476 gal/hr	75 wt %	0.5-1%	No	31%	42
Gulf Oil	Small home oil burner	No. 2 fuel oil	3 gal/hr	25 wt %	1.1%	No	28%	42
Northern States Power Company	Utility boiler (~500,000 lb steam/hr)	Coal	59,360 lb/hr	3.1 wt %	0.65%	Yes	24→61%[a]	61
Hawaiian Electric Co.	Utility boiler (~200,000 lb steam/hr)	No. 6 fuel oil	1,900 gal/hr	7.5%	0.45%	Yes	25→29%	62
Aberdeen Proving Ground, Edgewood Arsenal	Steam boiler (5,000 lb steam/hr)	No. 2 fuel oil	~40 gal/hr	30%	0.67%	No	~3%	63
Esso Research and Engineering	Steam boiler (~1,000 lb steam/hr)	None	7.5 gal/hr	100%	0.4→0.6%	No	<50%	57

[a] Based on analyses of collected precipitator flyash which contains ash from soot blowing operations.

Northern State Power Co., in their burning of a blend of 3 parts waste oil to 97 parts coal indicated a higher percentage emitted than 50 percent. Their estimate was based on an examination of the fly ash collected by their electrostatic precipitator as well as evaluation of the lead content of the flue gas down stream of the precipitator. Their flue gas analysis down stream of the precipitator showed no increase in lead content with the use of waste oil, as essentially all the lead-containing ash emitted from the boiler was collected as fly ash in the precipitator. A portion of this collected lead-containing fly ash, however, was generated during the short soot blowing operation (lasting approximately 5 minutes and performed twice per 8-hour shift), and not during normal operation. Section VIII, "Reduction of Impacts From Waste Oil Combustion," further examines the effectiveness of high efficiency particulate control systems for reducing emissions of lead and other trace contaminants found in waste oil.

The above information indicates that when waste oil is used as a fuel in systems with extensive heat transfer surfaces such as boilers, the quantity of lead emitted with the flue gas during normal operation (no perturbations experienced in the system such as during soot blowing startup and shutdown) should not exceed 50 percent of the lead entering the system.

For applications where heat transfer surfaces are not present such as firing waste oil in a rotary kiln or in incinerators, a higher percentage of lead emitted is possible. These cases would have to be evaluated on an individual basis to effectively estimate lead emissions. A recent study,[3] for example, shows that waste oil can be utilized as an auxiliary fuel in municipal incinerators without creating an adverse level of lead emissions. Many applications in which direct firing is used, such as rotary kilns, are inherently significant generators of particulate emissions. These processes would therefore require high efficiency control systems such as scrubbers and baghouses to meet emission regulations with or without the use of waste oil. Such processes which generally utilize high efficiency collectors potentially provide a good match for waste oil combustion. Section VIII discusses the impact reductions of lead and other trace waste oil contaminants obtainable with these high efficiency control systems and indicates those industries which utilize such control equipment and which therefore represent attractive potential users of waste oil as a fuel.

Particle Size Distribution of Pb and Other Waste Oil Contaminants Emissions

Tests were recently performed by Esso Research and Engineering[57] which included the combustion of 100 percent waste oil in a small (50 hp) boiler. The chemical composition and particle size distribution of the resulting particulate emissions were examined and these results, reported below, will serve as inputs to the discussion of control efficiencies of particulate collection systems discussed in Section VIII.

Table 14 shows the composition of the predominant trace contaminants present in the particulate emissions resulting from the combustion of waste oil.

Table 14. WT. PERCENT OF TRACE CONTAMINANTS IN PARTICULATE EMISSIONS FROM THE COMBUSTION OF WASTE OIL

	Contaminants					
	Pb	Ca	P	Zn	Fe	Ba
range	14 - 19	18 - 13	6.1 - 7.7	3.7 - 5.0	0.9 - 1.3	1.2 - 2.6
average	16	10	6.9	4.3	1.1	1.9

The particle size distribution of these trace components in the emissions was also determined by Esso and their results are summarized in Table 15.

Table 15. PARTICLE SIZE DISTRIBUTION OF LEAD AND OTHER MAJOR CONTAMINANTS IN EMISSIONS FROM WASTE OIL COMBUSTION (units: Wt. percent of the contaminant falling within the indicated particle size range)

	Pb	Ca	P	Zn	Fe	Ba
< 1 micron	76-79	10-19	23-42	56-73	2.7-36	3.3-51
1-10 micron	16-21	71-74	49-66	23-39	51-80	40-79
> 10 micron	2.7-4.4	10-15	8.9-10	3.4-5.0	13-18	8.9-18

Table 15 clearly indicates the submicron nature of the lead emissions. Zinc emissions are also significantly submicron in size. This information will serve as useful inputs to the discussion of control equipment examined in detail in Section VIII.

LEAD GROUND-LEVEL CONCENTRATIONS

Before waste oil can gain widespread acceptance as a suitable auxiliary fuel for use in industrial and utility boilers as well as other applications, the issue of its contribution to air quality degradation must be resolved. Because lead is both the most abundant trace element generally found in waste oil (800 → 11,000 ppm, see Section V) and the constituent considered most hazardous to public health, this discussion focuses on lead. Ground-level concentrations of other constituents can, however, be estimated from the lead concentrations presented in the ensuing discussion by scaling the lead concentration by the ratio of the emissions of constituent "X" to the emissions of lead as seen by equation (1).

$$\text{Conc}_X = \text{Conc}_{\text{lead}} \times \frac{\text{Emissions}_X}{\text{Emissions}_{\text{lead}}} \qquad (1)$$

where:

Conc_X = ground-level concentration of constituent "X"

$\text{Conc}_{\text{lead}}$ = ground-level lead concentration

Emissions_X = emissions in gms/sec (or equivalent units)

$\text{Emissions}_{\text{lead}}$ = lead emissions in gms/sec (or equivalent units)

At present national ambient air quality standards for lead have not been set and EPA has indicated that a previously proposed standard of 2 $\mu g/m^3$ — 3-month average may no longer be sufficient.[60] Consequently, contributions of ambient lead concentrations from sources burning waste oil need to be significantly less than 2 $\mu g/m^3$, averaged over 90 days, before a proposed application can be readily acceptable.

The information available on ground-level lead concentrations from current and projected applications of waste oil combustion, is summarized below in Table 16. Four applications are presented, for utilizing waste oil as a fuel, namely:

- In a domestic oil burner
- In industrial steam boilers
- In utility steam boilers
- As an auxiliary fuel in a municipal incinerator

In all the cases presented, particulate control equipment was not utilized. The estimated ambient air quality could, therefore, in theory be substantially reduced, if control equipment were employed. Section VIII presents a discussion of the effectiveness of control equipment in reducing lead emissions and indicates those industries which are currently utilizing such control systems.

In Test No. 4, waste oil is utilized as an auxiliary fuel in a domestic oil burner. Emissions from this test were used to estimate a maximum 1-hour average ground-level concentrations of 4 $\mu g/m^3$. This concentration is high relative to proposed levels of 2 $\mu g/m^3$ (average over 3 months or longer). Further testing is recommended to verify this ambient

Table 16. SUMMARY OF AVAILABLE ESTIMATES AND MEASUREMENTS OF AMBIENT LEAD CONCENTRATIONS RESULTING FROM WASTE OIL COMBUSTION

Test No.	Company	Location	Application	Virgin fuel type	Total fuel firing rate (gal/hr)	Waste oil firing rate (gal/hr)	Lead content in waste oil (wt %)	Stack height (ft)	Control device utilized	Soot blower utilized	Measured or calculated maximum ground-level concentration (μg/m³)	Concentration measurement classification	Reference number
1	Mobil Oil	Port Mobil, N.Y.	Auxiliary fuel in steam boiler	No. 6 fuel oil	100	5	1.0	60	None	Yes	1.0	Calculated 30-day average	42
2	Humble Oil	Sewell's Point, Virginia	Auxiliary fuel in steam boiler	None	100	100	Unknown	35	None	Yes	0.05 0.65^a	Measured short term sample	42
3	Shell Oil	Wood River Refinery	Auxiliary fuel in steam boiler	No. 6 fuel oil	374-476	280-476	0.5-1.0	130	None	Yes	0.2	Calculated 30-day average	42
4	Gulf Research & Development	Not referenced	Domestic oil burner	No. 2 fuel oil	3	0.8	1.1	15	None	No	4	Calculated 1-hour average	42
5	GCA/Technology Division	Northeast U.S.	Auxiliary fuel in municipal incinerator	None	300	300	1.0	100	None	No	0.05^b	Calculated 30-day average	3
6	Hawaiian Electric	Hawaii	Auxiliary fuel in utility boiler	No. 6 fuel oil	1,900	140	0.45	137	None	Yes	0.11	Calculated 1-hour average	62

[a] Based on ambient sampling during soot blowing.

[b] Concentration based on a specific set of operating conditions discussed in reference

concentration for the range of applicable burner designs and operational conditions. Assuming, however, that 4 $\mu g/m^3$ is representative, we feel that domestic heating and similar area source applications (low ground level, densely dispersed) is not desirable unless the lead content in waste oil is dramatically reduced. If for example, 0.1 $\mu g/m^3$ were an acceptable contribution to lead ambient concentration, the lead content in waste oil would have to be reduced by 97.5 percent $[(1 - 0.1/4)\ 100]$.

The tests numbered 1, 2, and 3 are all examples applying waste oil as an auxiliary fuel in industrial steam boilers. Emissions from tests 1 and 3 were utilized to estimate 30-day average ground-level concentrations, and in test No. 2, a short-term ambient sample was collected and its lead content measured. Although the resulting ambient concentrations differed significantly (0.05 → 1 $\mu g/m^3$), the data does illustrate that maximum ambient lead concentrations of less than or equal to 0.2 $\mu g/m^3$ can be achieved in industrial boilers when firing waste oil up to 360 gallons/hour.

Test No. 5 represents a theoretical estimate of ambient lead concentrations from the use of waste oil as an auxiliary fuel in a municipal incinerator. The maximum ground-level lead concentrations were estimated at 0.05 $\mu g/m^3$; the reader is referred to Reference 3 for further discussion of this application.

Test No. 6 is based on the firing of a 7.5 percent waste oil, 92.5 percent No. 6 residual oil blend in a 56-MW steam-electric utility boiler operating at 36 percent of capacity (20 MW). The 1-hour average maximum ground-level lead concentration was estimated at 0.11 $\mu g/m^3$. This result indicates that the impact from such an application is minimal (20 times smaller than the 2 $\mu g/m^3$ ambient level — 30-day average, being considered as the lead standard). The question remains, however, as to the potential impact of utilizing waste oil in a large utility boiler (> 500 MW) which services heavily populated urban areas. The modeling work discussed below which was performed as part of this study, addresses this specific and important application.

GCA has made preliminary estimates of ground-level lead concentrations averaged for two 1-month periods for a large New England power plant (560 megawatts) theoretically firing a 5 percent waste oil, 95 percent No. 6 fuel oil blend. The characteristics of this plant and the fuel oil blend being fired is summarized in Table 17.

The parameters in Table 17 were selected so as to approximate the "worst case" situation for generating adverse lead ambient concentrations. A 5 wt. % waste oil — 95 percent No. 6 residual oil blend — was chosen as it represents a firing rate of 1500 gallons/hour, which is the approximate maximum rate at which waste oil could be supplied for extended durations (see Page 78). A waste oil lead content of 1.0 percent was selected since previous discussions in this section indicated that this value was at the highest end of the spectrum for lead concentrations in waste oil. In addition, Table 13 presented earlier in this section showed that the

Table 17. ASSUMED PHYSICAL AND OPERATING CHARACTERISTICS OF 560 MEGAWATT POWER PLANT FIRING WASTE OIL

Physical Characteristics

- plant capacity: 560 MW
- number of stacks: 1
- stack height: 300 feet
- stack diameter: 18 feet

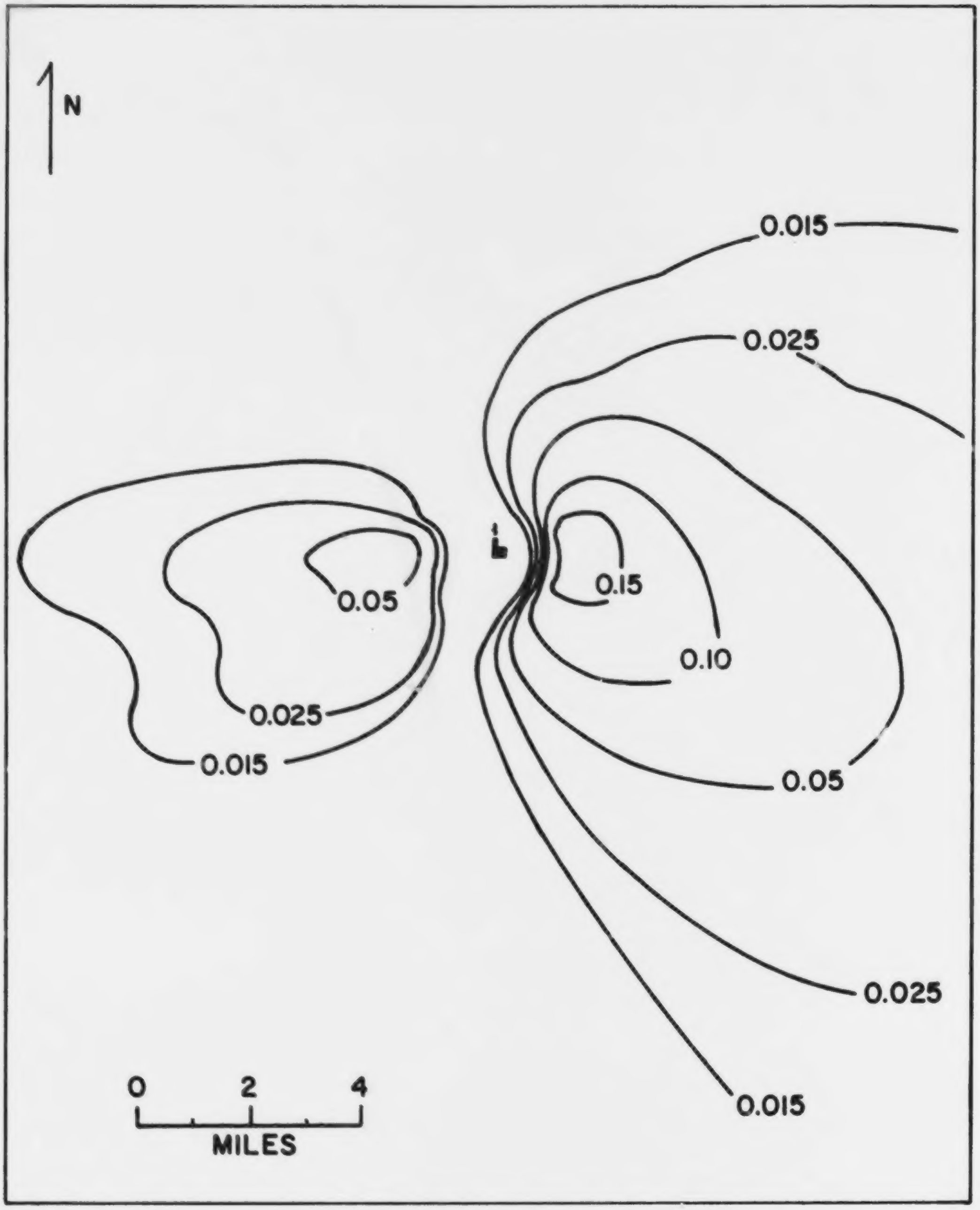
Operating Characteristics

- continuous operator - 7 days per week
- type of fuel: 95 wt. percent No. 6 residual oil
  5 wt. percent - waste automotive oil
- waste oil lead content: 1.0 wt. percent
- lead emitted with flue gas as a percentage of lead entering with oil: 50%
- average fuel feed rate: 17,600 barrels/day ≡ 31,000 gallons/hour
- average heat content of fuel blend: 146,000 BTU/gallon
- gas exit temperature: 149° C
- gas exit velocity: 84.0 feet/second

highest ratio of lead out of the stack to lead entering with the waste oil approximated 50 percent, this value was utilized here. And finally, we choose to estimate average lead concentrations over a 1-month period rather than a 3-month average (the 3-month average has been advocated most recently as the time frame associated with proposed lead ambient standards), since shorter time periods result in higher average concentrations.

Average ground-level concentrations expected over a 1-month period in the vicinity of a selected New England power plant were calculated by means of a Gaussian diffusion model for an elevated point source. Estimates of effective stack height for use in the model were made using an expression developed by Briggs.[64] Hourly wind speeds and directions for the calculations were measured at the plant site.

Results of the calculations for 2 months (September and December 1970), presented in Figures 7 and 8, show maximum ground-level concentrations of slightly more than 0.10 and 0.15 $\mu g/m^3$. These maximum values are in good agreement with the value presented in Table 16 for a smaller utility boiler. More important, they are an order of magnitude smaller than the concentrations proposed as the ambient standards for lead. Consequently, this preliminary environmental impact assessment supports the use of untreated waste oil in large utility boilers as a fuel-blending component. GCA recommends, however, that ambient monitoring of lead concentrations from such an application be performed to verify the diffusion model and associated assumptions made in this analysis.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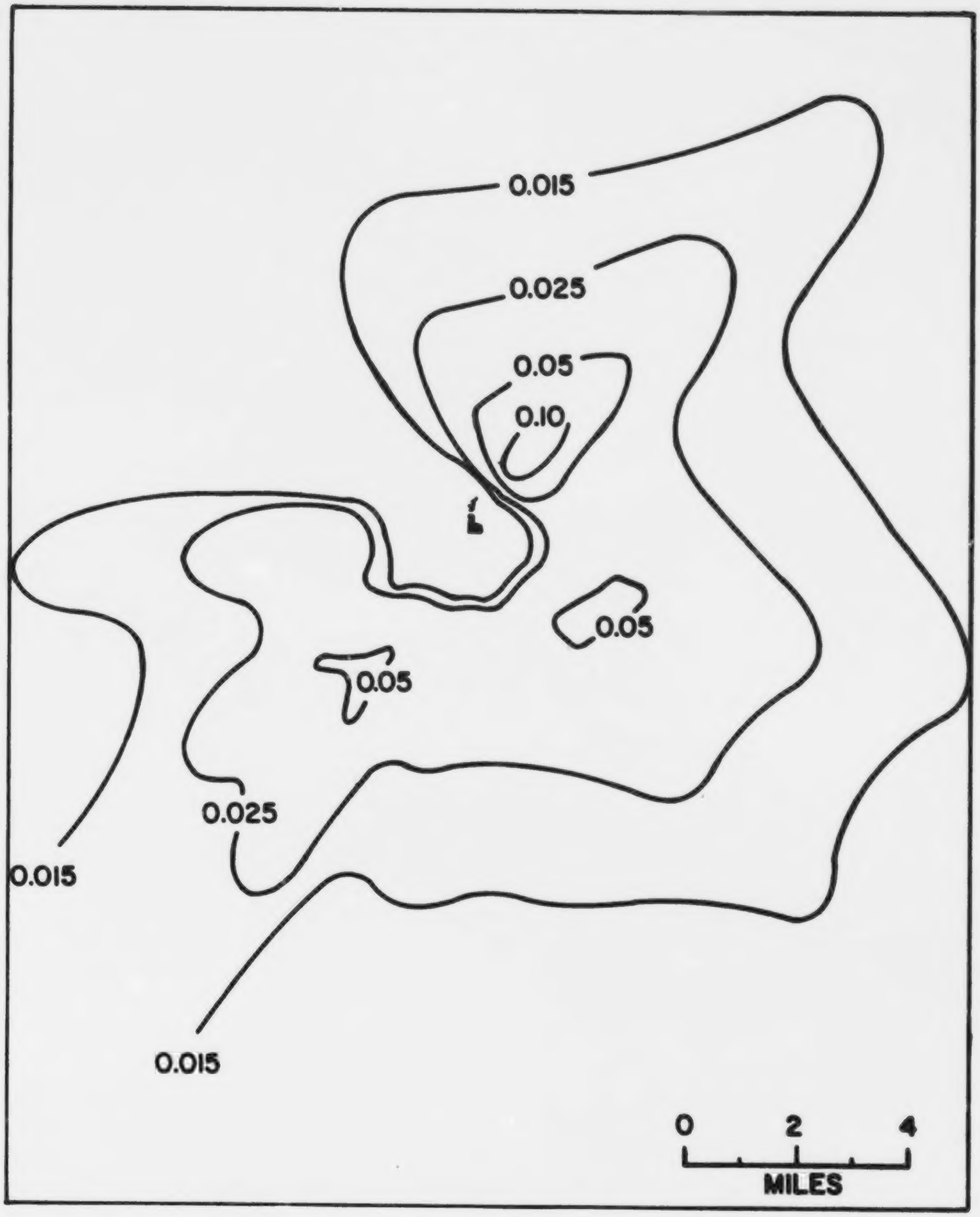
4
MILES

Figure 7. Isopleths of average ground-level concentration of Pb for December 1970. Units are $\mu g/m^3$.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MILES

Figure 8. Isopleths of average ground-level concentration of Pb for September 1970. Units are $\mu g/m^3$.

SECTION VIII

REDUCTION OF WASTE OIL FUEL COMBUSTION IMPACTS

WASTE OIL IMPUTITIES AND THEIR IMPACTS

Before reviewing some of the possible waste oil fuel impact reduction alternatives, a brief re-examination of the contaminants that occur in waste oil and their effects on its use as a fuel will be made. These contaminants can be broken down into three categories:

1. Volatile contaminants
2. Soluble contaminants
3. Insoluble contaminants

Volatile contaminants are primarily gasoline, water, and chlorinated hydrocarbons. Gasoline can be present in amounts up to 10 percent. Water similarly ranges from 1 to 10 percent. The water is present as either free water, emulsified water, or oil-soluble water. Both free and emulsified water, when present in sufficient quantities, can freeze and cause blockages of unheated fuel lines.[31] Burner flameout and variable heating value are also attributable to the presence of this water in waste oil. Soluble water is present in trace amounts and therefore is not an important factor when considering waste oil as a fuel. On the other hand, the soluble chlorinated hydrocarbons found in waste oil form combustion products that are capable of producing adverse visibility and health effects.

Soluble contaminants also include metal-organic additives and polymeric viscosity index additives. Elements such as zinc, phosphorus and sulfur are present to a significant extent as soluble contaminants. Lead, zinc, iron, barium, calcium, and magnesium compounds are present to a lesser extent as soluble metal organic additives. The aforementioned soluble compounds do not seriously affect the storage, handling, and combustion of waste oil. Upon combustion, combustion products may be formed that are capable of producing adverse visibility and health effects and the fouling and corrosion of boiler heat transfer surfaces. Insoluble compounds are primarily atmospheric dust, carbon, and finely dispersed metal or metallic oxide particles. Suspension of these particles in oil is generally aided by the presence of the still active detergents in waste oil. These particles are derived from fuel combustion, corrosion or abrasion of engine parts and from the degradation of metallic organic additives in either gasoline or the lubricating oil itself. The principal metallic contaminant is lead which may be present to the extent of 1 percent. Other metals that are present in concentrations higher than those of other conventional liquid fuels are zinc, iron, barium, calcium, and magnesium. Coarse solids in waste oil contribute to the abrasive wear of nozzles, pumps, and valves, can plug lines and burner strainers and lead to excessive sludge buildup in storage tanks. Fine metallic solids can cause fouling and corrosion of boiler heat transfer surfaces. Most of the harmful metallic constituents in waste oil exist as submicron size particles. Lead is the primary constituent of the waste crankcase oil ash, accounting for approximately 35 percent of the total ash content.[57] These fine metallic particles would be the principal source of adverse environmental emissions as a result of the uncontrolled utilization of waste oil as a fuel.

WASTE OIL FUEL COMBUSTION IMPACT REDUCTION ALTERNATIVES

The potential impacts of untreated waste oil utilization as a fuel and several impact reduction alternatives are presented in Table 18. This table classifies the properties affecting waste oil fuel utilization as:

1. Specific gravity
2. Water
3. Coarse solids
4. Ash forming materials

Impact reduction as a result of blending has already been discussed in Section VI. The three impact reduction alternatives that will be considered in this section are low-level pretreatment processes, high-level pretreatment processes, and particulate emission control equipment. A detailed discussion of the capital and operating costs of these impact reduction systems will be presented in Section IX.

As illustrated by Table 18, the combustion of untreated waste oil can lead to added maintenance, fouling, and corrosion of boiler heat exchange surfaces and environmental contamination. The primary function of low-level pretreatment operations is to remove volatile materials and coarse solids in order to minimize the abrasive wear of nozzles and valves as well as to produce a fuel of consistent heating valve. Low-level pretreatment will keep operating and maintenance costs associated with feed and burner systems comparable to those incurred with conventional fuels. However, low-level pretreatment does little to remove the metallic constituents in waste oil and subsequently does not significantly reduce the fouling and corrosion of boiler heat exchange surfaces or emission of metallic contaminants that would result from waste oil combustion. In order to obtain significant metallic contaminant removal, high-level pretreatment techniques must be utilized.

Table 18. POTENTIAL IMPACTS AND IMPACT REDUCTION ALTERNATIVES OF UNTREATED WASTE OIL UTILIZATION AS A FUEL

Property	Potential impacts	Impact reduction alternatives
Specific gravity	Formation of concentration gradients in combined storage tanks with distillate oils	• Storage in tanks that accomplish mixing via convectional heating coils. • Separate storage with blending just prior to combustion.
Water	Fuel line freezing	• Use with heated fuel lines. • Removal of water prior to use (low-level pretreatment).
	Burner flameout	• Use with auxiliary torch to sustain burner flame.
	Inconsistent heating value	• Use for temperature insensitive application. • Removal of water prior to use (low-level pretreatment).
Coarse solids	Sludge buildup in storage tank to point of drawoff	• Storage in tanks with bottom sludge removal drains. • Use with dispersant emulsifiers to keep sludge in suspension. • Removal of sludge prior to use (low-level pretreatment).
	Line strainer fouling	• Removal of sludge prior to use (low-level pretreatment).

Table 18 (continued). POTENTIAL IMPACTS AND IMPACT REDUCTION ALTERNATIVES OF UNTREATED WASTE OIL UTILIZATION AS A FUEL

Property	Potential impacts	Impact reduction alternatives
Coarse solids (cont)	Abrasion of positive displacement pump seals	• Separate waste oil storage plus transport prior to blending with hardened impeller centrifugal pumps. • Removal of sludge prior to use (low-level pretreatment).
	Abrasion of burner nozzles	• Use with wide orifice hardened nozzles. • Removal of sludge prior to use (low-level pretreatment).
Ash forming materials	Health hazard to boiler cleaning crew	• Use of respirators during cleaning. • Removal of ash forming materials prior to use (high-level pretreatment).
	Scaling and corrosion of heat transfer surfaces	• Use in direct-fired furnaces. • Removal of ash forming materials prior to use (high-level pretreatment).
	Hazardous emissions	• Use with efficient particulate emission control equipment. • Removal of ash forming materials prior to use (high-level pretreatment).
	Ash disposal problems	• Removal of ash forming materials prior to use (high-level pretreatment).

Low-Level Pretreatment

Filtration is perhaps the most common method of achieving liquid-solid separations. All petroleum fuel oil handling factilities utilize this unit operation if only in the form of simple strainers. Self-cleaning edge type filters are often used but are ineffective for particles smaller than 40 microns. They remove abrasive grit but do not affect the metal content to any great extent. Effective filtration of micron-sized particulates can only be achieved by fine pore structure media which are expensive and costly to operate. In general, the cost of filtration varies inversely with the size of the particles to be filtered.

Filtration can be effective if the particle size of the suspended particles can be altered by chemical treatment. It is frequently used following acid/clay treatments to contain the high metal sludges for subsequent treatment.

Settling is the simplest means of removing that portion of the BS&W not held in suspension by the oil and its dispersants. Separation is by gravity. The rate of settling can be increased by heating the oil, thus lowering its viscosity. Since most of the particulates, carbon, metallic and atmospheric dust particles in waste oil are less than 1 micron in diameter this procedure is not an effective means of lowering contaminant levels. The effectiveness of settling is illustrated by Table 19 which gives calculated settling rates of particles (3.0 g/cc, Sp. Gr.) in a typical waste oil at 100°F.

Table 19. SETTLING OF PARTICLES IN 100°F WASTE OIL

Particle diameter (μm)	Time to settle through 1 ft
0.1	40 years
1.0	160 days
5.0	6.5 days
10	1.6 days
100	25 minutes

At 200°F the settling rates would be 5 to 10 times greater but still too low to be effective for all but the largest particulates. Although settling is largely ineffective in removing fine contaminant, it does remove coarse grit and free water, and is usually the first method employed in any treatment process. In the transfer of oil from storage tanks provision should always be made for withdrawal of oil from a level well above the BS&W level in the tank and for withdrawal of BS&W at periodic intervals from the bottom of the tank. This is standard operating procedure and is the simplest form of contaminant removal by settling. More rigorous treatments would involve controlled settling at high temperatures or with a diluent added to reduce oil viscosity.

Rates of settling can be greatly enhanced by centrifugation. Commercial units can produce forces many thousands of times that of gravity, reducing settling times accordingly. For a separating force of 10,000 times that of gravity a 1-micron particle such as that listed in the above table will settle 1 foot in about 25 minutes. Although commercial units are not considered effective for 1 micron and smaller particles, they can completely remove particulates and water droplets 3 to 5 microns in diameter. The oil is usually heated prior to centrifugation to lower the viscosity as much as possible. Another technique, used in ASTM procedures, is to further lower viscosity by dilution of the oil with an oil soluble solvent such as naptha or toluene. Demulsifiers are sometimes used to allow coagulation of suspended particles and water droplets to occur and increase separation in the centrifuge. In summation, centrifuging is technically feasible for processing large volumes of oil but cannot be expected to lower ash and metallic contaminant levels appreciably because of their fine particle size.

Demulsification, followed by one of the aforementioned solid-liquid separation methods, is a technique used by some processors of wate oil. One such waste oil reprocessor has reported lowering the BS&W content to a maximum of 1.5 percent by using a demulsifier followed by a centrifuge.[66] Demulsifiers are mixed with oil to counteract the effect of the still active emulsifiers present in waste oil which keep water and solids in suspension. Demulsification is most successful in removing suspended water. Solids are more difficult to remove, although surfactants that wet the surfaces of these solids are reportedly useful. This treatment, usually carried out at elevated temperatures (~200°F), does not remove small particles and therefore is categorized as a low-level pretreatment.

The removal of the volatile components of waste oil can be effectively achieved by thermal processes which drive off the low boiling contaminants. Flash distillation at atmospheric or reduced pressures is a common technique. Some re-refiners, however, depend upon the thermal inputs used for operations such as settling or centrifugation to drive off most of the water and low boiling fuels. Volatiles are condensed and water is separated from immiscible organic liquids by decantation operations.

Two low-level pretreatment systems are discussed in detail below. An economic analysis of these systems is presented in Section IX.

Settling System - As indicated by Figure 9, this process is a batch operation. Initially, the untreated waste oil is put into a tank fitted with a drain to facilitate the removal of any sediment and water that settles out during storage. After storage, a portion of the solids remaining in the raw oil is removed by coarse and fine strainers. Centrifugal pumps are employed to transport raw waste oil due to abrasion and viscosity considerations. Pumping rates should be sufficiently high to ensure that solid materials do not settle out in transport lines. After straining, caustic soda is metered into the process stream in order to neutralize or make basic the previously acidic waste oil. A demulsifier is then metered into the oil stream to enhance the settling of solids remaining in the oil. After the addition of these chemicals, the oil is then heated to 300°F in a plate heat exchanger. Due to the roughness of the heat exchange surfaces, turbulent flow is achieved, even at low flow rates. As a result, the carbonization of waste oil on heat exchange surfaces is minimized. Once heated, the oil is agitated to ensure adequate demulsifier-oil contact as well as enhance the vaporization and removal of low boiling point solvents and water. These vapors are condensed and the solvent phase is separated from the water phase and stored. After agitation, solid materials are allowed to settle out of the hot oil. When sufficient settling has taken place, the finished oil product is removed and stored while the settled sludge is removed and centrifuged. The oil reclaimed by this centrifugation is returned to the original raw oil storage tank while the thickened sludge is stored for eventual incineration.

Centrifugation System - As shown in Figure 10, this process is a continuous operation. Storage, straining, pumping, and chemical additive accommodations for the untreated waste oil are the same as they were for the settling process. After the addition of caustic soda and demulsifier, the oil is heated to 200°F in a plate heat exchanger. Once heated, the oil passes through a self-cleaning centrifuge where a good portion of the solids and water is removed. Ninety percent of the effluent stream is stored as finished product while 10 percent is recycled back into the process stream just prior to the heat exchanger. The sludge and water resulting from the centrifugation operation is stored for eventual incineration.

High-Level Pretreatment

Techniques such as ultrafiltration and membrane dialysis are theoretically capable of obtaining fine particle separations but are impractical because of the high solids content of waste oil. Other methods or combination of methods such as demulsification, electrolytic deposition, flocculation, and coagulation could also be used. None of these latter methods or combination of methods appear commercially suitable at this time for the separation of the many metallic constituents from a product as variable as waste crankcase oil. Metals separation by such treatments or combination of treatments does appear possible, but would require extensive laboratory and pilot plant development to establish

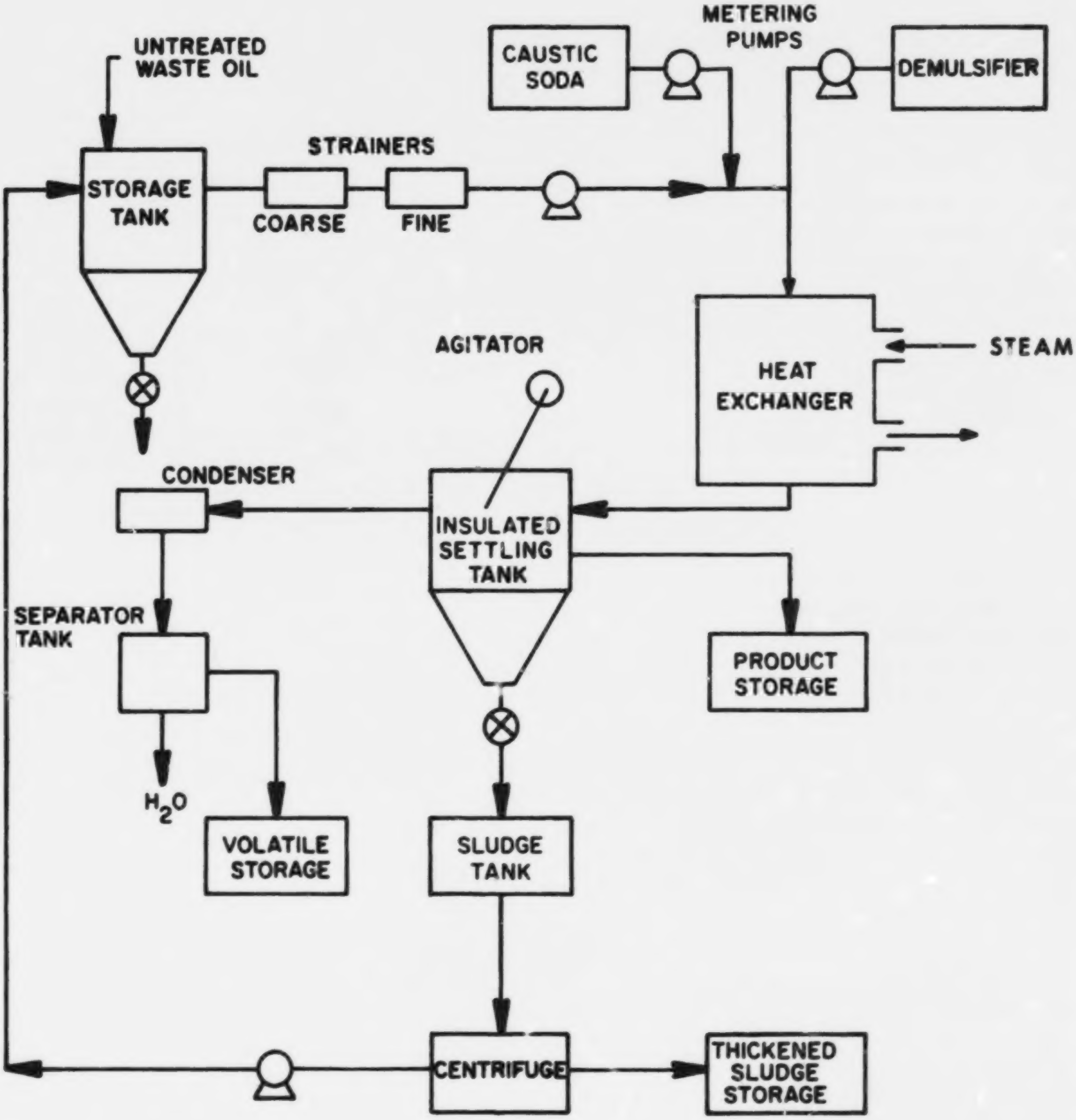
UNTREATED WASTE OIL
STORAGE TANK
STRAINERS
COARSE
FINE
CAUSTIC SODA
METERING PUMPS
DEMULSIFIER
STEAM
HEAT EXCHANGER
AGITATOR
CONDENSER
INSULATED SETTLING TANK
SEPARATOR TANK
PRODUCT STORAGE
H_2O
VOLATILE STORAGE
SLUDGE TANK
CENTRIFUGE
THICKENED SLUDGE STORAGE

Figure 9. Settling pretreatment

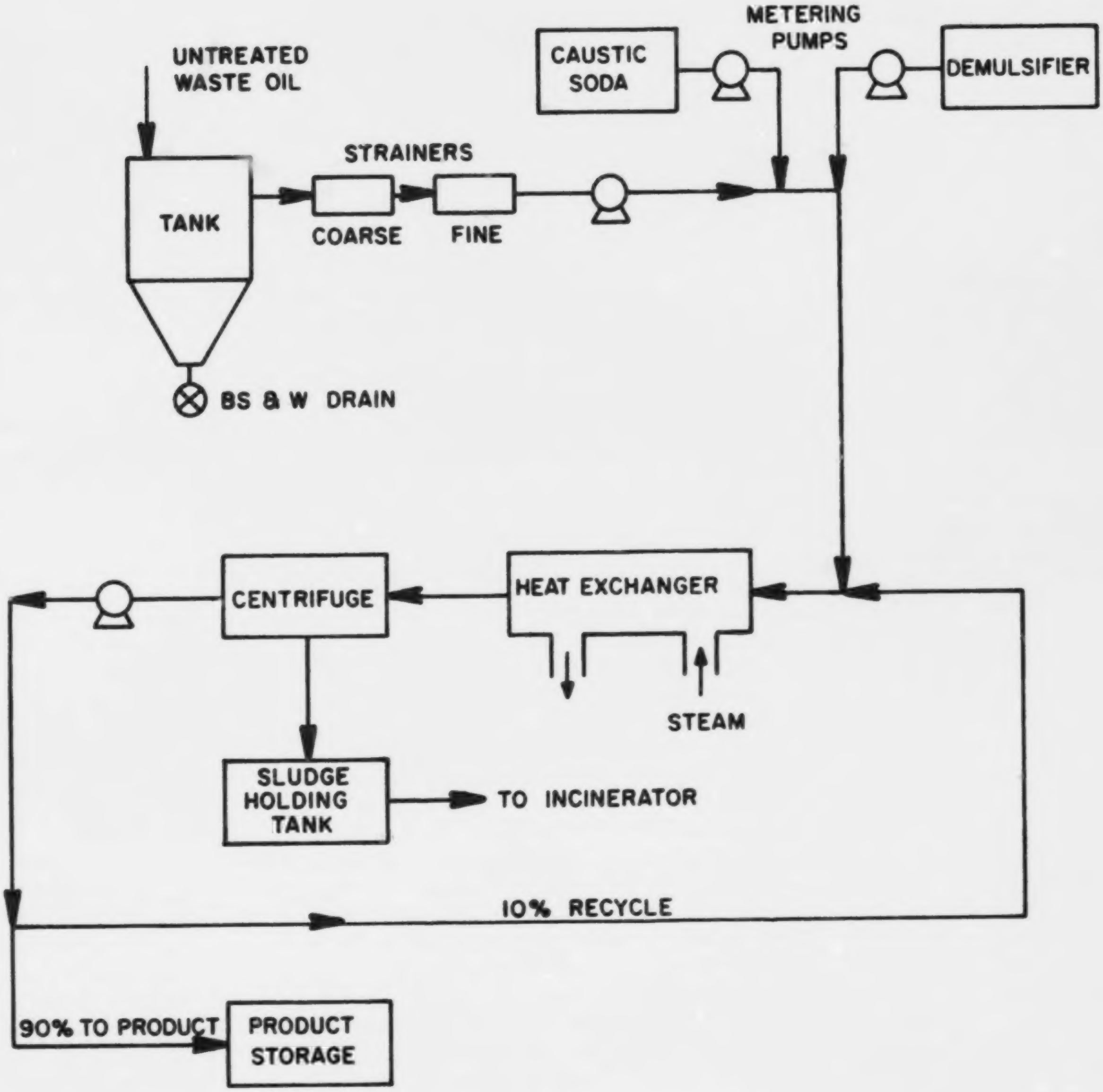
UNTREATED WASTE OIL
TANK
STRAINERS
COARSE
FINE
BS & W DRAIN
CAUSTIC SODA
METERING PUMPS
DEMULSIFIER
HEAT EXCHANGER
STEAM
CENTRIFUGE
SLUDGE HOLDING TANK
TO INCINERATOR
10% RECYCLE
90% TO PRODUCT
PRODUCT STORAGE

Figure 10. Centrifugation pretreatment

feasibility. There are, however, three treatments that are presently used to effect the removal of metallic contaminants. These are acid/clay treatments, solvent extraction and vacuum distillation. The remainder of this discussion will be concerned with these three methods.

Acid/clay treatment was at one time the principal method of refining waste oil. When using this technique, waste oil is contacted with sulfuric acid to remove the metals and oxidized products followed by clay treatment to remove trace materials including those contributing to color and odor. A number of variations on this process exist including the combination of acid/clay treatment with distillation, but all yield large quantities of acid and clay wastes. A flow diagram of a continuous acid/clay operation followed by vacuum fractionation is shown in Figure 11.[67]

In the conventional acid/clay process, large amounts of concentrated sulfuric acid and clay are used. In a typical process, 9 percent of a concentration (98 percent) sulfuric acid solution and 7 percent of the clay utilized ends up as a waste product. The disposal of these oil contaminated acid wastes and sludges poses extremely difficult problems and accounts for the decline in the use of this approach by oil processors. Although clay incineration is desirable, extremely efficient control devices would be necessary to prevent escape of metallic constituents into the atmosphere. The disposal of large volumes of corrosive acid wastes is even more troublesome. Since detrimental ecological impacts are likely to be incurred as a result of the disposal of these wastes, we do not consider acid/clay treatment of waste oil an ecologically sound technique.

Solvent extraction is a reportedly effective means of separating metallic constituents and other solvent insoluble contaminants from waste oil. Unfortunately, it has not been extensively utilized in this country for the re-refining of waste oils. However, a commercial process involving solvent extraction of waste oil is being operated in Italy, under a license to the Institut Francais Du Petrole. This plant uses propane to extract the desirable oil fraction in a manner similar to that used in a propane deasphalting process in the petroleum industry (see Figure 12). Some acid clay treatment is reportedly required, presumably to obtain good quality lube oil. The amounts of acid and clay needed are only 10 to 20 percent of that normally used in an acid/clay treatment. This treatment would probably not be necessary in a plant concerned solely with fuel oil production.

Solvent extraction processes have been considered by several other waste oil investigators. Environmental Quality Systems, Inc., in a study for the State of Maryland, has proposed solvent extraction as a primary technique for waste oil recovery. A flow diagram of their proposed system is shown in Figure 13. Unfortunately, design details and cost estimates have not yet been presented in any detail.

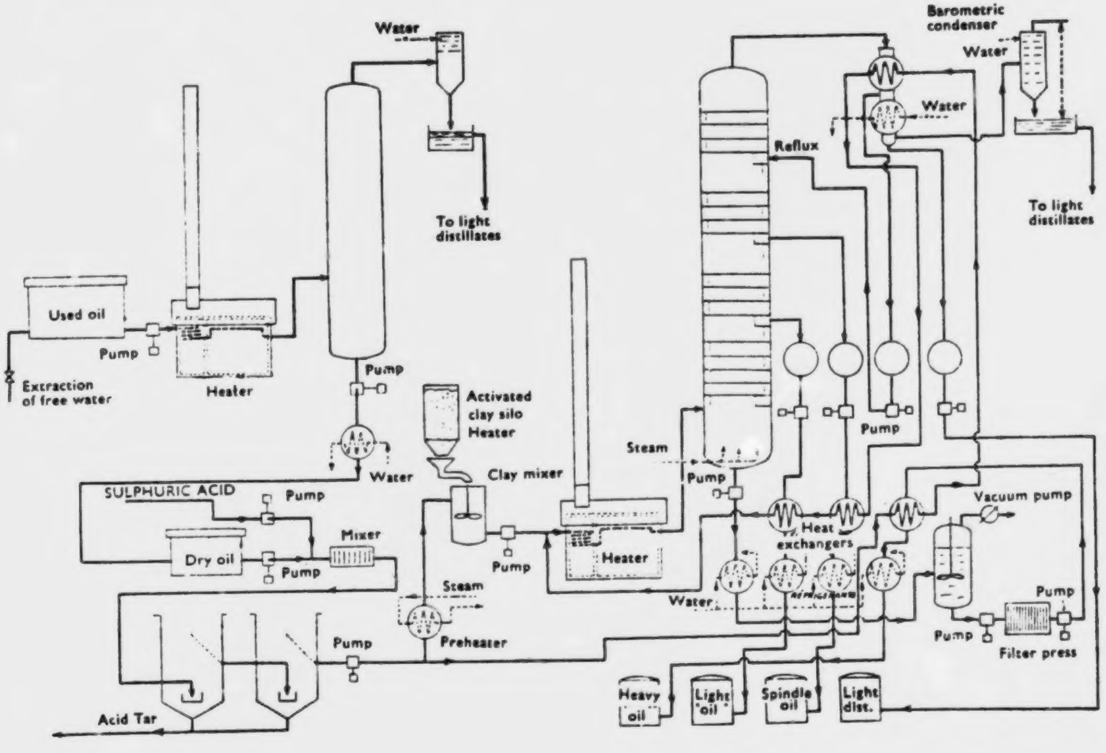
Used oil
Pump
Extraction of free water
Heater
Water
Pump
To light distillates
Water
SULPHURIC ACID
Pump
Dry oil
Pump
Mixer
Acid Tar
Pump
Steam
Preheater
Activated clay silo Heater
Clay mixer
Pump
Heater
Steam
Pump
Reflux
Barometric condenser
Water
Water
To light distillates
Pump
Heat exchangers
Water
Vacuum pump
Pump
Pump
Filter press
Heavy oil
Light oil
Spindle oil
Light dist.

Figure 11. Flow diagram of continuous acid/clay unit for the reclamation of used motor oils with capacity of 15,000 tons per annum

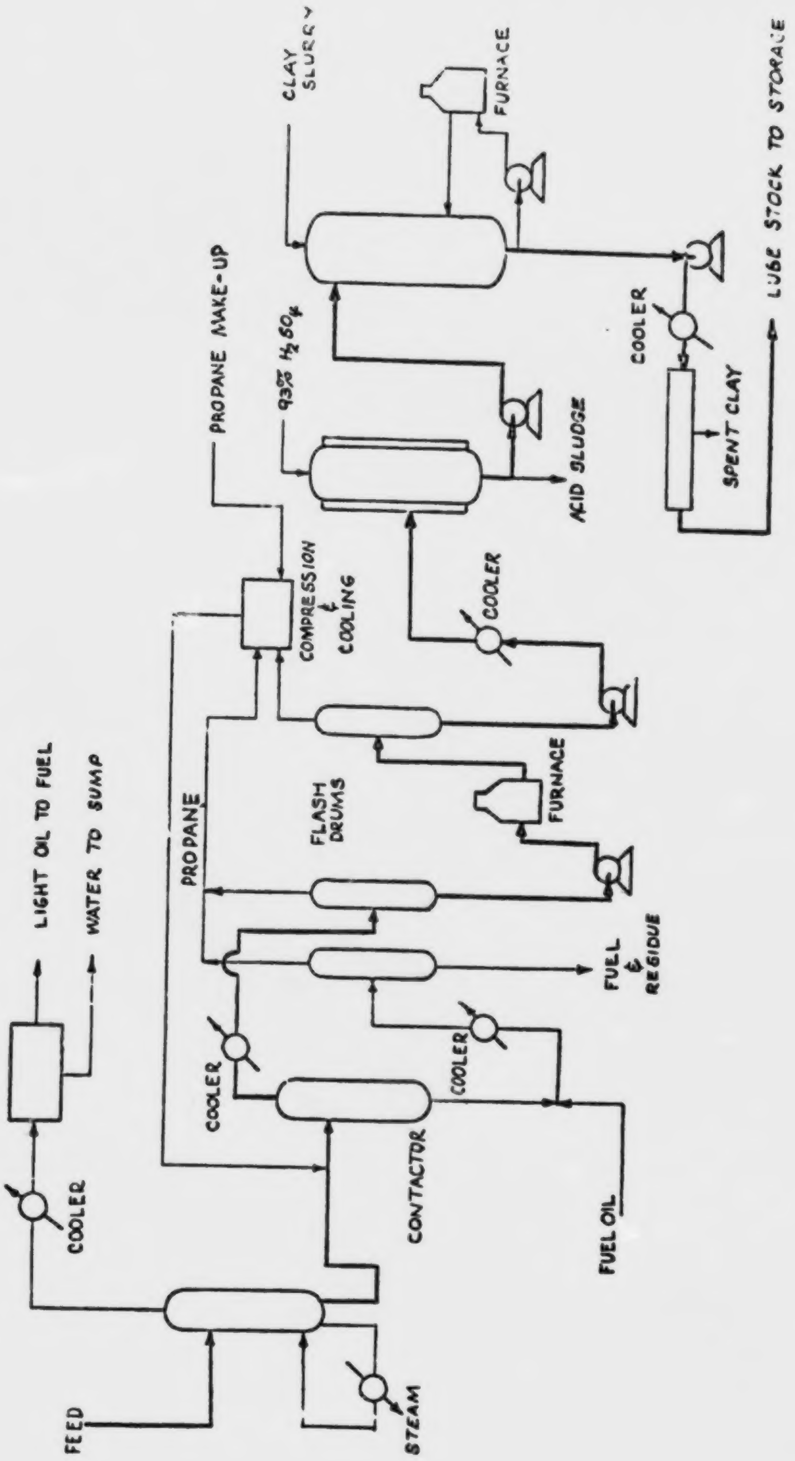
FEED
STEAM
COOLER
LIGHT OIL TO FUEL
WATER TO SUMP
CONTACTOR
FUEL OIL
COOLER
COOLER
PROPANE
FUEL & RESIDUE
FLASH DRUMS
FURNACE
COMPRESSION & COOLING
COOLER
PROPANE MAKE-UP
93% H_2SO_4
ACID SLUDGE
CLAY SLURRY
FURNACE
COOLER
SPENT CLAY
LUBE STOCK TO STORAGE

Figure 12. Re-refining by a propane extraction process[68]

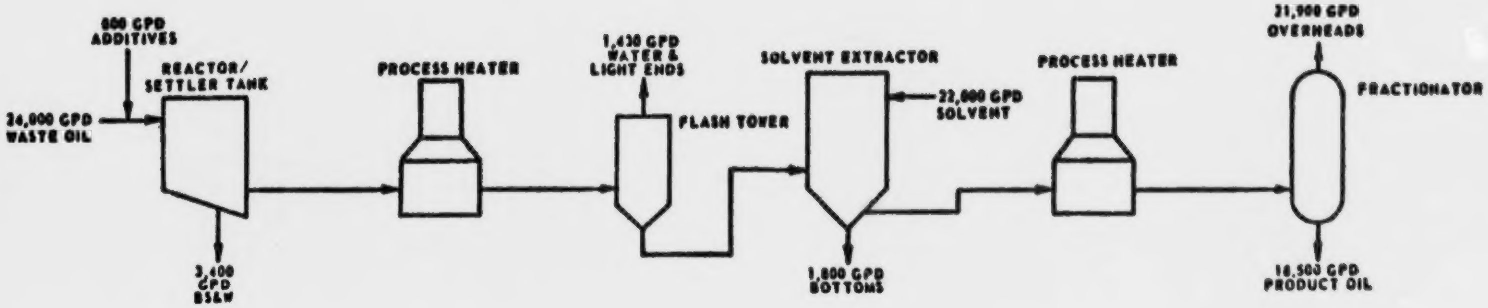
800 GPD ADDITIVES
24,000 GPD WASTE OIL
REACTOR/ SETTLER TANK
3,400 GPD BS&W
PROCESS HEATER
1,430 GPD WATER & LIGHT ENDS
FLASH TOWER
SOLVENT EXTRACTOR
22,000 GPD SOLVENT
1,800 GPD BOTTOMS
PROCESS HEATER
21,900 GPD OVERHEADS
FRACTIONATOR
18,500 GPD PRODUCT OIL

Figure 13. Solvent treatment subsection[69]

Recon Systems, Inc., also has considered the economics of solvent extraction techniques to be used in conjunction with vacuum distillation and hydrofining operations. They have concluded that the use of solvent treatment may improve the operability of subsequent vacuum distillation steps but question the direct applicability of solvent treatment without subsequent operations such as distillation and hydrofining to upgrade the product. Their concern is largely based on the desirability of maximizing production of the more costly lube oils relative to fuel oils.

The above studies have been seriously restricted by the lack of experimental evidence which would define the effectiveness of solvent treatment and characterize the resultant product. A limited laboratory study of a solvent treatment process has been carried out by Esso Research & Engineering Company in a study for the State of Massachusetts.[57] In this study metal removal ranges from 70 to 97 percent with the variability due to variations in the oil samples and in the choice of solvent used. Some elements, notably zinc, phosphorus and sulfur, were not effectively removed, probably because of the greater solubility of their compounds in the oil phase. The results of some tests are shown in Tables 20 and 21.[57]

In this study the waste oil samples were mixed with five times their volume of solvent (e.g., one part n-hexane, nine parts n-propyl alcohol), and centrifuged. The oil containing the solvent was then decanted from the sludge and distilled to effect a separation of solvent and oil.

Norco has also conducted small scale studies of solvent extraction (naphtha solvent) followed by distillation.[70] Their proposed system is shown in Figure 14. The final distilled product was free of particulates and metals. However, this process should be further evaluated on a larger scale to determine if this high quality product can be achieved in a commercial facility.

The volume ratio of solvent to oil used in the Esso study was five. This ratio was needed for effective separation of liquid and sludge in the centrifuge. This ratio is appreciably greater than the 1:1 ratio proposed by Environmental Quality Systems, Inc., and used by Norco in their studies. High solvent ratios would adversely affect the economics of the process because of the need to separate solvent and oil by distillation of the solvent.

Although this method of treatment is attractive from the standpoint of trouble-free operation and low sludge disposal requirements, not enough is now known about the process and its effectiveness for variable waste oil feedstocks to design and cost such a system with a high degree of confidence. We recommend further laboratory and design studies be instituted as soon as possible.

Re-refiners of waste oil commonly use vacuum distillation techniques to recover waste oil. This process is used generally with some sort

Table 20. MAJOR ELEMENT ANALYSIS ON ENGINE LAB OIL[57]

Sample	Ash 1000°F	Ba	Ca	Pb	Fe	Zn	P	S
Original oil (wt %)	5.22	0.22	0.28	2.00	0.08	0.09	0.18	0.31
Recovered oil (wt %)	0.27	<0.02	0.02	<0.05	0.01	0.04	0.05	0.22
% removal	95.	>91.	93.	>97.	88.	56.	69.	29.
Sludge (wt %)	25.	1.20	1.40	12.	0.40	0.40	0.44	--
Material balance (%)	99.	110.	105.	≈120.	109.	124.	80.	>57.

NOTE: Hexane and n-propyl alcohol were utilized as the solvent for precipitation and excellent phase separation was obtained.

Table 21. REMOVAL OF MAJOR ELEMENTS FROM USED OIL[57]

Waste oil samples	Ash 1000°F	Ba	Ca	Pb	Fe	Zn	P	S	Run No.
Stripped DePalma oil	71.[a]	--	63.	88.	>50.	50.	40.	9.	27
Engine lab oil	95.	>91.	93.	>97	88.	56.	69.	29.	31
Engine lab oil	98	>91.	>96.	>98.	>88.	67.	81.	42.	33
Service station oil	72.	61.	63.	75.	60.	55.	44.	29.	40
Service station oil	83.	83.	81.	90.	>80.	64.	56.	34.	42

[a] The number represents the percentage decrease in weight of the element or ash in going from the original to the treated oil.

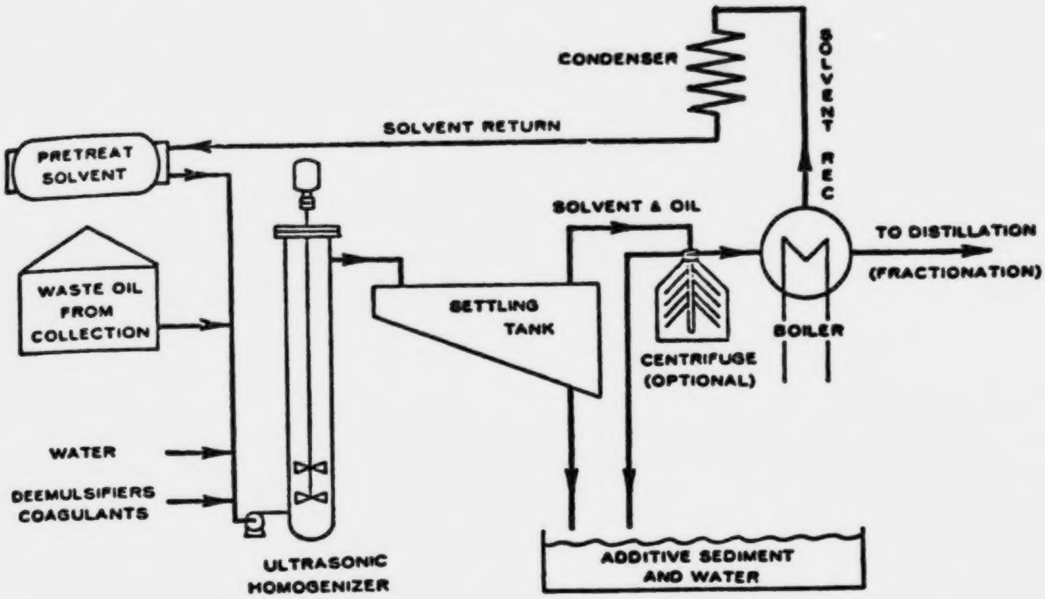
CONDENSER
SOLVENT REC
SOLVENT RETURN
PRETREAT SOLVENT
SOLVENT & OIL
TO DISTILLATION
(FRACTIONATION)
WASTE OIL FROM COLLECTION
SETTLING TANK
BOILER
CENTRIFUGE (OPTIONAL)
WATER
DEEMULSIFIERS COAGULANTS
ULTRASONIC HOMOGENIZER
ADDITIVE SEDIMENT AND WATER

Figure 14. Norco solvent extraction system[70]

of pretreatment operation to remove at a minimum most of the free water and sediment. It can be used, of course, in combination with a variety of pretreatment operations, including the acid/clay and solvent precipitation process discussed above. The Norco vacuum distillation system is shown in Figure 15.

Most refineries, such as Norco, are interested in the separation of the waste oil into lube oil and other fractions that have offered in the past greater cost return due to their higher market value. However, for processes designed solely for fuel oil production, such fractionation is not necessary and adds to the cost of equipment and its operation. For fuel oil grade product it is only necessary that the process be relatively free of operational problems and that the fuel oil is relatively free of volatiles, metallic constituents, and tarry sediment which could either present safety problems, foul equipment, or provide unfavorable environmental impact in subsequent combustion operations.

Bottoms disposal is still a problem since the bottom fraction contains a high percentage of the metallic constituents that were left behind in the distillation. The bottoms, depending upon the operating conditions of distillation, can vary from possibly 10 percent to a much greater percentage of the total feed, with the metals content varying inversely. The Norco process as shown in Figure 15, produces 22 percent bottoms product. A 20-percent bottoms residue will contain approximately 10 percent ash, mostly metallic compounds. This residue can be further processed to remove usable fuel oil by techniques that are usually based on solvent extraction processes. One such technique is that developed by Universal Oil Products and Petrolios Mexicano for the separation of high-metal content vacuum residues. This technique requires the effective segregation of metals in the solvent phase. Such a technique does not appear to be economically justifiable here. Recon Systems, Inc. has proposed that bottoms disposal can be accomplished by the sale of this material to lead processors. At present the economic feasibility of such a disposal practice has not been established. Bottoms incineration can be considered but the predominantly submicron-sized particles in the exhaust gases will require utilization of high-efficiency filter baghouses or electrostatic precipitators to avoid excessive lead and other metal particulate emissions.

For purposes of fuel oil production, vacuum distillation appears satisfactory provided fouling of surfaces can be minimized by effective pretreatment or through the use of anti-fouling additives. This fouling is due to not only metallic constituents, but to tarry substances that result from the reaction of gasoline blowby products with the oil to form carbonyls and nitrated compounds. Anti-foulants originally in the oil are apparently decomposed and rendered ineffective at distillation temperatures. High temperature anti-fouling agents added to the waste oil prior to distillation have apparently proved to be effective in tests at Norco, reducing both equipment fouling and tar deposits.[70]

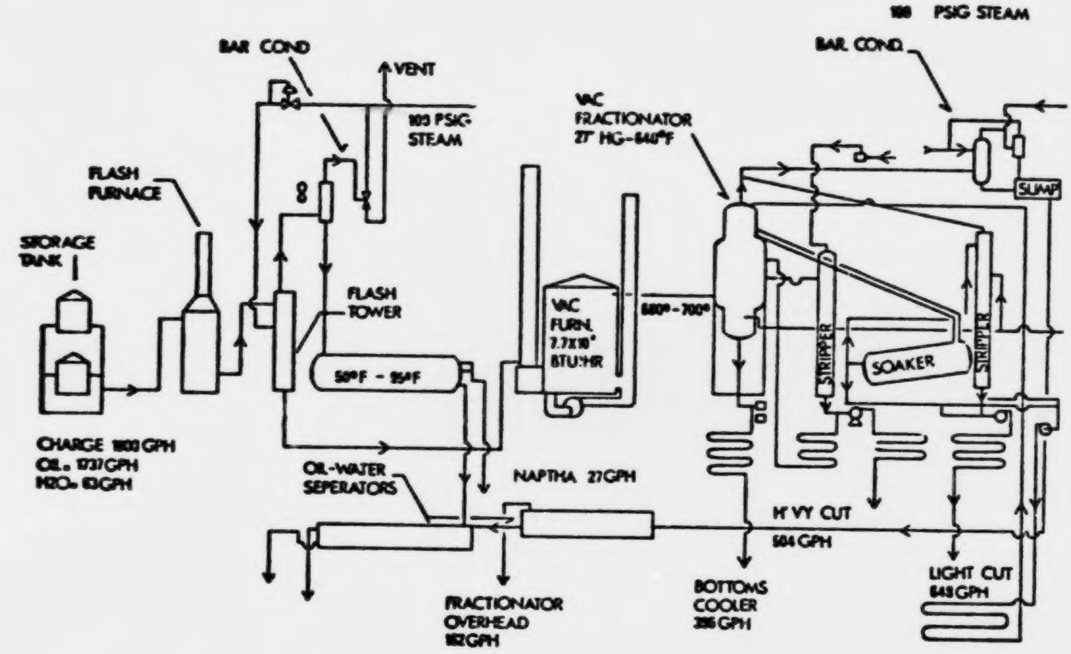
100 PSIG STEAM
BAR COND
VENT
BAR COND.
100 PSIG STEAM
VAC FRACTIONATOR 27" HG–640°F
FLASH FURNACE
SUMP
STORAGE TANK
FLASH TOWER
VAC FURN. 7.7X10^6 BTU:HR
680°-700°
STRIPPER
SOAKER
STRIPPER
50°F - 95°F
CHARGE 1800 GPH
OIL = 1737 GPH
H2O = 63 GPH
OIL-WATER SEPERATORS
NAPTHA 27 GPH
H'VY CUT
504 GPH
FRACTIONATOR OVERHEAD 182 GPH
BOTTOMS COOLER 386 GPH
LIGHT CUT 648 GPH

Figure 15. Norco re-refining facility[70]

A waste oil distillation system should be as simple as possible without fractionation into multiple phases. By operating at the lowest practical temperature, fouling and coking are minimized. Maximization of the distillation product can be achieved by operating at reduced pressure or in the presence of an inert gas such as steam.

Two high-level pretreatment systems are discussed in detail below. As was the case for low-level pretreatment, the economic analysis of these systems is presented in Section IX.

Solvent Extraction System - Perhaps the primary advantage of a solvent extraction system is the relatively small quantities of high metal content sludge produced. It is also a low temperature process and should be relatively free of maintenance and fouling problems. A major disadvantage appears to be the failure to achieve complete separation of the metallic constituents.

The process, as shown in Figure 16, has not been worked out in detail. Its applicability will depend upon the effectiveness of the solvent used to precipitate metallic constituents. We have arbitrarily chosen naphtha as the solvent although other solvents such as those used in the Esso study[57] could be used. A naphtha-oil ratio of 1 was used. The choice of naphtha (end point 310°F) is conservative from the standpoint of thermal requirements since other suggested solvents are for the most part lower boiling solvents.

Separation of precipitated contaminants is accomplished by continuous centrifugation in a manner related in the Esso study and various ASTM standards for the determination of sediment. An extraction column such as is used in the French process was not used because of the lack of design details. Contact times required for precipitation of contaminants can be adjusted by variations in mixing tank size and design prior to centrifugation. Following centrifugation the high metals content sludge is concentrated in a second centrifuge to reduce solvent and oil losses. The sludge may be further processed to recover solvent in a vacuum system that utilizes surface condensers and a mechanical vacuum pump to avoid water contamination and additional separation operations. Other sludge disposal alternatives are controlled sludge incineration or sale to a secondary metal processor. Sludge incineration is questionable in terms of the environmental impacts that might be created while sludge mining by a metal processor is economically unproven.

Vacuum Distillation System - The vacuum distillation process is used today by a number of refiners who process waste oil to recover lube oil products. A process for the production of fuel oil would be very similar. The major difference is in the design of the fractionating tower. A process for the production of fuel oil would not require the fractionation of the distillate into multiple cuts and would not require multiple condensation and storage facilities for the various distillate

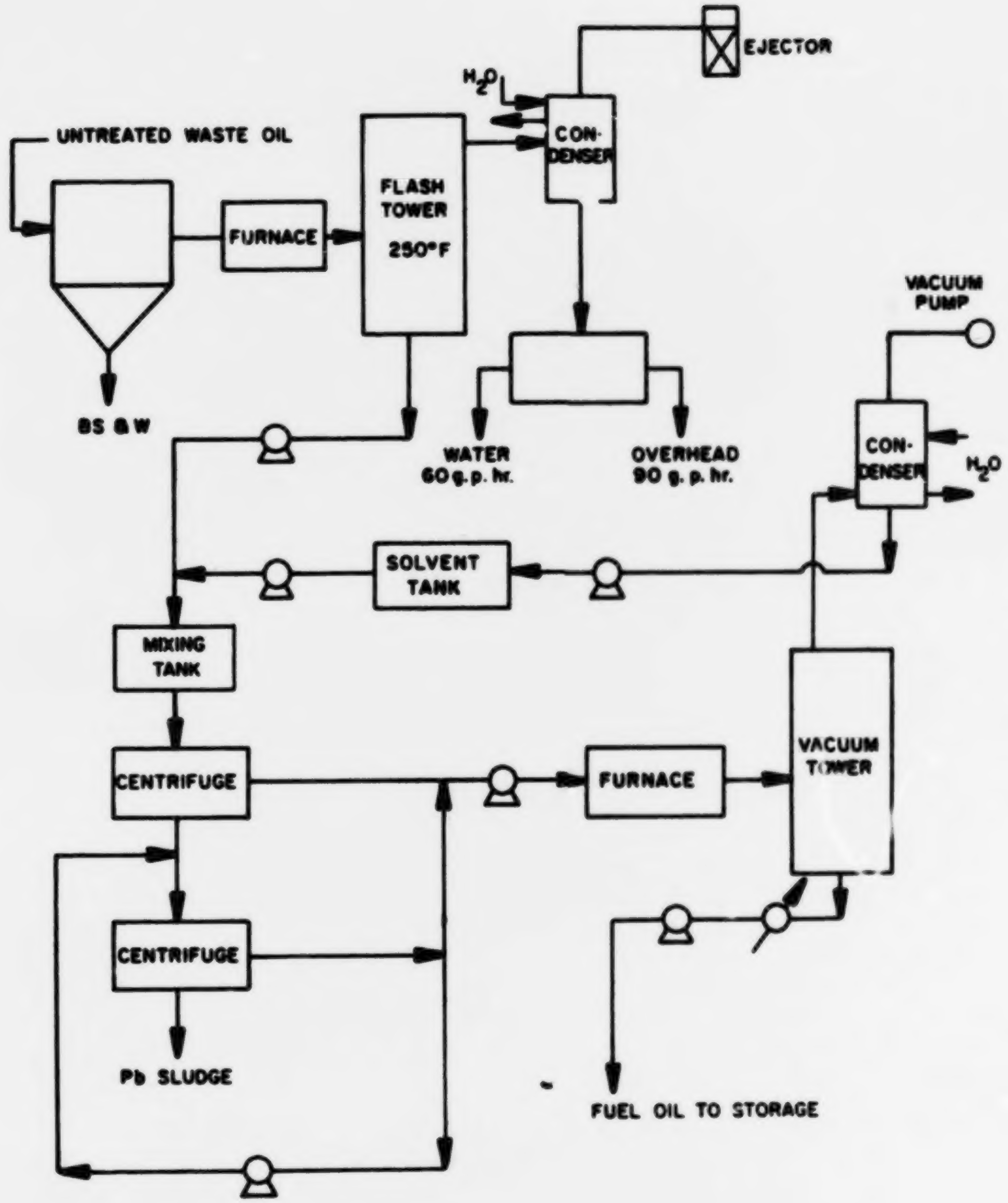
EJECTOR
H_2O
CONDENSER
UNTREATED WASTE OIL
FURNACE
FLASH TOWER
250°F
VACUUM PUMP
BS & W
WATER
60 g.p.hr.
OVERHEAD
90 g.p.hr.
CONDENSER
H_2O
SOLVENT TANK
MIXING TANK
CENTRIFUGE
FURNACE
VACUUM TOWER
CENTRIFUGE
Pb SLUDGE
FUEL OIL TO STORAGE

Figure 16. Solvent extraction process

products. Although fuel oil production involving separation of essentially one distillate from the bottoms is simpler and less costly than lube oil production, its market value is less than that of lube oil.

The vacuum distillation process does appear to be technically feasible providing a solution can be found to two major problem areas noted previously. The first problem results from the fouling of boiler tubes by the contaminants in the waste oil. The second problem concerns the disposal of the high metals content bottom fraction. A bottoms content of 17 percent is obtained from the process shown schematically in Figure 17. Although the bottoms fraction could be reduced by a change in operating conditions (i.e., vacuum and temperature), the changes are likely to be costly in terms of both capital equipment and operating costs. A lower limit of bottoms content is probably about 10 percent in any event. The disposal of this material can be carried out in well-controlled incineration equipment. However, it may be possible to sell these bottoms to secondary metals processors for lead recovery as suggested by Recon Systems, Inc.

The plant, as shown in Figure 17, is essentially that now in operation at the National Oil Recovery Corporation. To reduce fouling and sediment, a centrifuge has been added between the flash unit and the vacuum unit heater. Fouling can also be reduced by close attention to tubes and furnace design and by the injection into the oil of anti-foulants. These have been used with some success at Norco.

Comparison of Pretreatment Systems

In the section of a waste oil pretreatment system to reduce the technical and environmental impacts associated with combustion, several alternatives are possible. If blending and/or the use of particulate emission control equipment acceptably reduces the maintenance, operational, and environmental penalties of waste oil combustion, no pretreatment is necessary. Oftentimes, however, added maintenance costs and/or potentially harmful lead emissions will make waste oil pretreatment necessary.

The quality of fuel oil that would be produced by the two low-level pretreatment processes considered is adequate for trouble-free combustion in conventional fuel burning equipment. However, low-level pretreatment does little to reduce hazardous emissions and boiler fouling and corrosion which result from the high metallic content of waste oil. In order to reduce this metallic content and subsequently alleviate this problem, high level pretreatment must be used.

It is difficult to quantify the effectiveness of the low-level pretreatment systems considered because of such factors as the variability of feed stock, the effectiveness of demulsification, etc. However, in Table 22, GCA has attempted to estimate the effectiveness of low-level pretreatment systems in removing various classes of contaminants from a typical waste oil product. These estimates were based on manufacturers

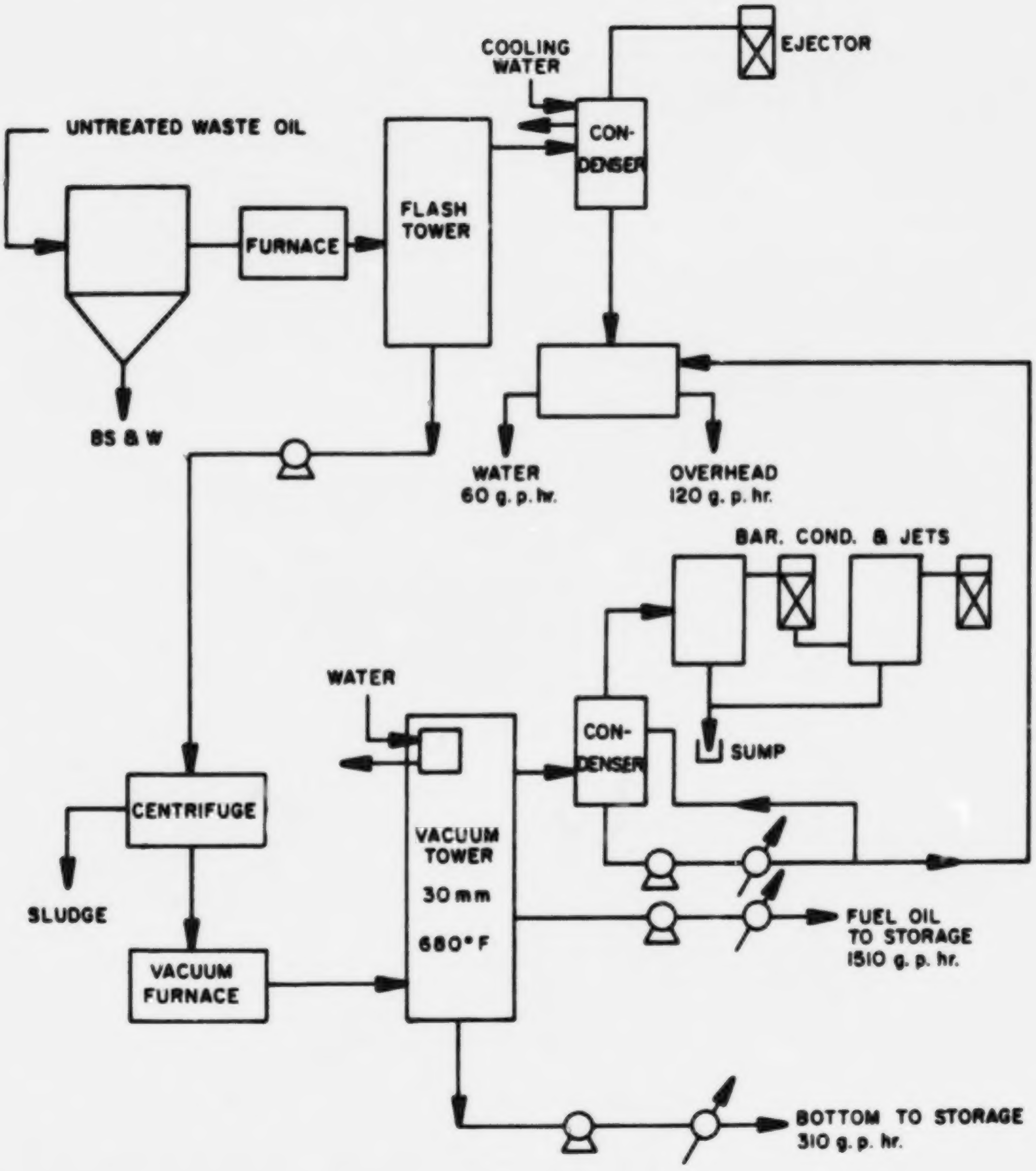
COOLING WATER
EJECTOR
UNTREATED WASTE OIL
CON-DENSER
FURNACE
FLASH TOWER
BS & W
WATER 60 g. p. hr.
OVERHEAD 120 g. p. hr.
BAR. COND. & JETS
WATER
CON-DENSER
SUMP
CENTRIFUGE
VACUUM TOWER
30 mm
680°F
SLUDGE
VACUUM FURNACE
FUEL OIL TO STORAGE 1510 g. p. hr.
BOTTOM TO STORAGE 310 g. p. hr.

Figure 17. Vacuum distillation treatment

Table 22. WASTE OIL CONTAMINANT REMOVAL BY TREATMENT PROCESSES

Treatment process	Approximate waste oil concentration after pretreatment				
	BS&W (vol. %)	H_2O (vol. %)	Ash (wt. %)	Pb (wt. %)	Sediment (wt. %)
No treatment (untreated waste oil)	10	8	3	1	5
Settling pretreatment	1.0	0	2.3	0.9	2.5
Centrifugation pretreatment	1.5	1	1.5	0.75	1.7
Solvent extraction	0.3	0	0.3	0.1	0.3
Vacuum distillation	0	0	0	0	0

performance claims and present understanding of contaminant distributions in waste oil. They are given here to indicate the general level of contaminant removal that may be expected by pretreatment processes and are contrasted with removal levels anticipated with high-level treatment systems.

With regard to low- and high-level pretreatment, one must be aware of the residues that result. Low-level pretreatment yield a fuel of high metal content and a waste residue of low metal content while the reverse is true for high-level pretreatment. Disposal of high metal content residues is a problem that should not be discounted. If improper disposal techniques are employed, high-level pretreatment will have only shifted rather than alleviated the environmental impact of waste oil utilization as a fuel.

Particulate Emission Control

The emission of lead and other contaminants resulting from the combustion of waste oil can be significantly reduced by the employment of high efficiency pollution control equipment. This method of environmental impact reduction is a particularly viable one for those industrial sectors that combine high fuel consumption with a high incidence of high efficiency particulate control device utilization. These areas are likely potential users of waste oil since they can combust waste oil without significantly increasing air contaminant levels and without incurring cost penalties for extensive pretreatments and the installation of control devices.

The following discussion will examine the control equipment suitable for the efficient collection of waste oil combustion particulate matter and the fuel oil combustion and control practices of electric utilities and the industrial sector of the economy.

High Efficiency Emission Control Equipment - There are only three methods of particulate control which are applicable to the reduction of environmental impacts resulting from waste oil combustion. Fabric filtration, electrostatic precipitation, and the high energy venturi scrubber are the only control methods which will provide efficient removal of the predominantly submicron-sized particles that constitute the bulk of the lead and zinc emissions. The particle size distribution of combusted waste oil was depicted previously in Table 15. Through combustion testing it has been shown that greater than 75 (wt) percent of the lead particles generated by the combustion of waste oil are submicron in size.

Although fractional efficiency measurements for submicron particles are not readily available in the literature, it is recognized that the fabric filter baghouse is the most efficient device for submicron-sized particles. A properly operated and maintained baghouse is capable of achieving efficiences greater than 99.99 percent for 0.5 micron diameter particulates.[71] Electrostatic precipitators are somewhat less efficient but have been used for fine, submicron-sized dusts such as those from open hearth and for basic oxygen furnaces in the steel industry at efficiencies of 95 to 99 percent.[72] Particle sizes are comparable to those emitted during waste oil combustion. Electrostatic precipitators have the advantage of low pressure drop and are preferred for many applications such as combustion flue gas cleaning because of this. They also are capable of operation at temperatures which are somewhat higher than high temperature baghouses. Both control devices, however, must be carefully designed, operated, and maintained to ensure a high level of control for specific effluent gas and particle conditions. If this is done, efficient collection of 0.3 to 1.0 micron-sized particles is possible and at least one and possibly two orders of magnitude reduction of emissions are obtainable.

As illustrated by Figure 18, high energy venturi scrubbers are only marginally suitable for submicron particle collection. The low efficiency and high energy requirements of these scrubbers, when applied to fine particle emissions, are disadvantages.

Electric Utility and Industrial Fuel Consumption Patterns - The consumption of fossil fuels by electric utilities and industry has been discussed in some detail in Section IV. In that section coal and oil consumption data were presented as a function of the various two-digit SIC industrial classifications. Additional information concerning the fuel oil consumption patterns of utilities and selected industrial categories is given below in Table 23. The industrial categories listed are primarily in the metals and minerals industries. These industries were considered to be the most likely users of waste oil fuels, based upon their high rate of fuel consumption and their employment of particle control devices. As will be discussed in detail later in this section, not all of the industries listed in the table are logical users of waste oil, since in some cases processing considerations will not tolerate the contaminant levels associated with waste oil combustion. Illustrative of this is the concern of the cement industry about possible deleterious effects associated with the presence of soluble lead, zinc, and phosphorous compounds in the cement product. A similar concern would apply to the sale of fly ash for use by cement manufacturers when obtained from collection devices installed at power plants utilizing waste oil.

Electric Utility and Industrial Particulate Control Equipment Utilization - The major air pollutants emitted from combustion of coals and petroleum fuels in steam-electric power plants and other industrial processes are: (1) particulate matter, (2) sulfur oxides, and (3) nitrogen oxides. Due to increasingly stringent environmental control regulations, a wide range of process and stack gas emission control devices is currently being employed. This enhances the feasibility of waste oil fuel usage and removal of hazardous particulate emissions without a large additional outlay of capital for control hardware installation.

The electric utility industry, as discussed above and in Section IV, is by far the largest consumer of fuel oil in the United States. Although control equipment, primarily electrostatic precipitators, is used by

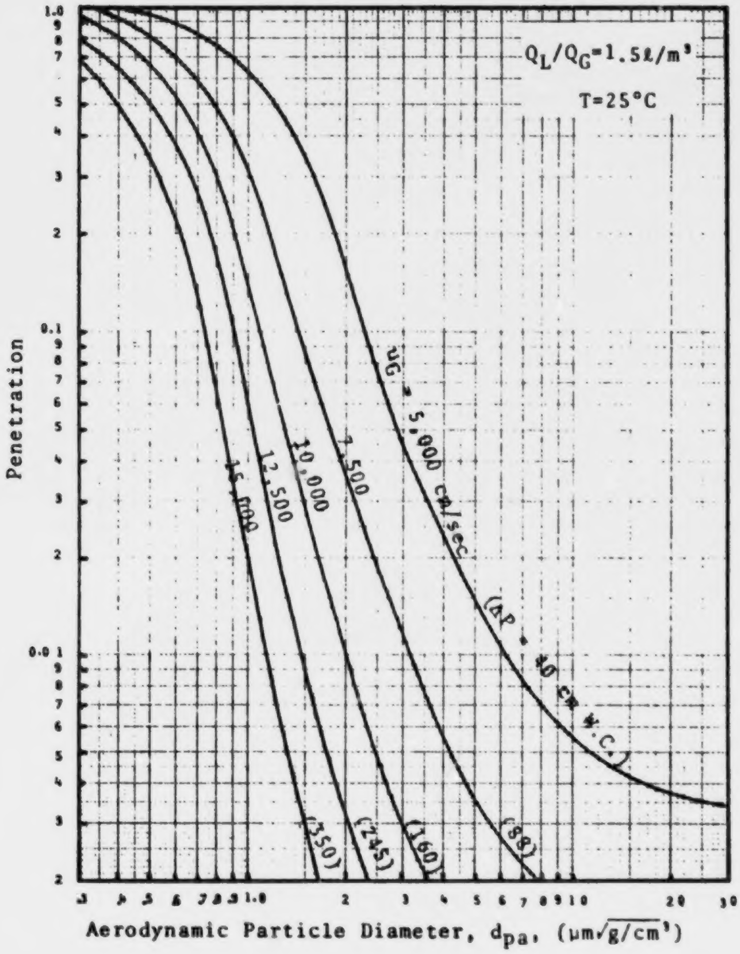

Figure 18. Venturi scrubber penetration vs. aerodynamic particle diameter with gas velocity as parameter.

Table 23. FUEL OIL CONSUMPTION PRACTICES OF POTENTIAL INDUSTRIAL WASTE OIL USERS[14]

Potential waste oil using industry	SIC No.	Total fuel oil consumed in 1967 (10^3 bbl)
Turbo electric power plants	4911	137,500
Paper mills	2621	16,620
Steel mills	3312	30,859
Primary copper	3331	1,575
Primary lead	3332	34
Primary zinc	3333	N/A
Primary aluminum	3334	143
Primary non-ferrous metals	3339	104
Secondary non-ferrous metals	3341	575
Hydraulic cement (i.e.,Portland)	3241	2,611
Mineral wool	3296	N/A
Clay refractories	3255	N/A
Lime	3274	401
Brick and structural tile	3251	694
Gypsum products	3275	828
Concrete block and brick	3271	319

this industry, they have been applied almost exclusively to coal burning facilities. Coal burning operations in 1969 accounted for over 99 percent of particulate emissions from all utilities. The particulate emissions from oil and gas burning operations are well below those required by federal or state ambient air quality standards. Consequently, electrostatic precipitators are not normally installed by plants burning only fuel oil. Precipitators existing on oil-fired units were usually installed prior to conversion of the unit from coal to oil operations. The efficiency of these units, designed for coal combustion, will probably be low. Hazardous emissions resulting from waste oil combustion will increase accordingly. Waste oil usage should be considered only in those situations where efficient particulate collection is realized if environmental impacts are to be mitigated by control devices.

In addition to electric utilities, many industrial boilers and processes are equipped with precipitators, fabric filter baghouses, and high energy venturi scrubbers. Table 24 summarizes the electrostatic precipitator installations in major fields of application through 1957.[72] Although this information is badly dated, the areas of usage are still applicable. Sales figures of control devices in 1967 are shown in Table 25 for various industrial sectors. An indication of the growing rate of installation of air pollution control devices is given in Figure 19.[71]

As a first order approximation, those end users that combine high fuel consumption patterns with the employment of high efficiency collection devices would appear to be the best suited for use of waste oil fuel. Table 26 qualitatively depicts the industrial usage of such collection devices. Although the classifications are somewhat different, there is a high degree of correlation between the users of collection equipment and industrial consumers of fuel oil as previously shown in Table 23. However, not all industrial processes using control devices are combustion operations. Many, for example, involve purely physical operations such as crushing or grinding. As mentioned previously, where process fuel is used, contamination factors must also be considered for specific cases such as cement manufacture, black liquor recovery in the Kraft industry and in many segments of the metals industry. While there are no such constraints applicable to industrial heating and steam generating facilities, they are not likely to be equipped with control devices when oil is used as the primary fuel. As with electric power plants, industrial power plants are large potential users of waste oil fuel, but except for coal-fired units, they do meet the criterion of combining high fuel consumption with efficient particulate control.

An examination of the process and pollution control literature and the questionnaire survey results (see Appendix D) does indicate some potential for waste oil usage in operations involving control devices. Positive indication of interest were obtained from firms engaged in the following controlled operations and industries:

Cement kilns
Metallurgical coke ovens

Table 24. SUMMARY OF UNITED STATES PRECIPITATOR INSTALLATIONS IN MAJOR FIELDS OF APPLICATION, 1907 TO 1957[72]

Application	First installation	Number of precipitators	Gas flow, million cfm
Electrical power industry (fly ash)	1923	730	157
Metallurgical:			43.4
Copper, lead, and zinc	1910	200	15
Steel industry	1919	312	22.5
Aluminum smelters	1949	88	5.9
Cement industry	1911	215	29
Paper mills	1916	160	18
Chemical industry	1907	500	9
Detarring of fuel gases	1915	600	4.5
Carbon black	1926	50	3.3
Total		2,855	264.2

Table 25. INDUSTRIAL GAS CLEANING EQUIPMENT--MANUFACTURERS' SHIPMENTS BY END USE, 1967 (thousands of dollars)[71]

End use	Electrostatic precipitators	Scrubbers, particulate	Mechanical collectors	Fabric filters
Iron and steel	5,783	7,423	2,300	4,536
Utilities	15,506	--	2,476	--
Chemicals	1,207	3,709	3,130	5,344
Rock products[a]	2,760	1,142	1,038	3,602
Paper and pulp	--	989	802	122
Mining and metallurgical	--	825	389	1,855
Refinery	--	--	--	--
All other[b]	687	3,901	8,408	4,959
Exports	--	651	--	1,081
Total shipments	36,509	19,229	22,381	21,730

[a] "Rock products" includes cement and asbestos plants.

[b] "All other" includes shipments to distributors where end use cannot be identified.

Ref: Business and Defense Services Administration, U.S. Department of Commerce, Industrial Gas Cleaning Equipment Shipments and End Use - 1967.

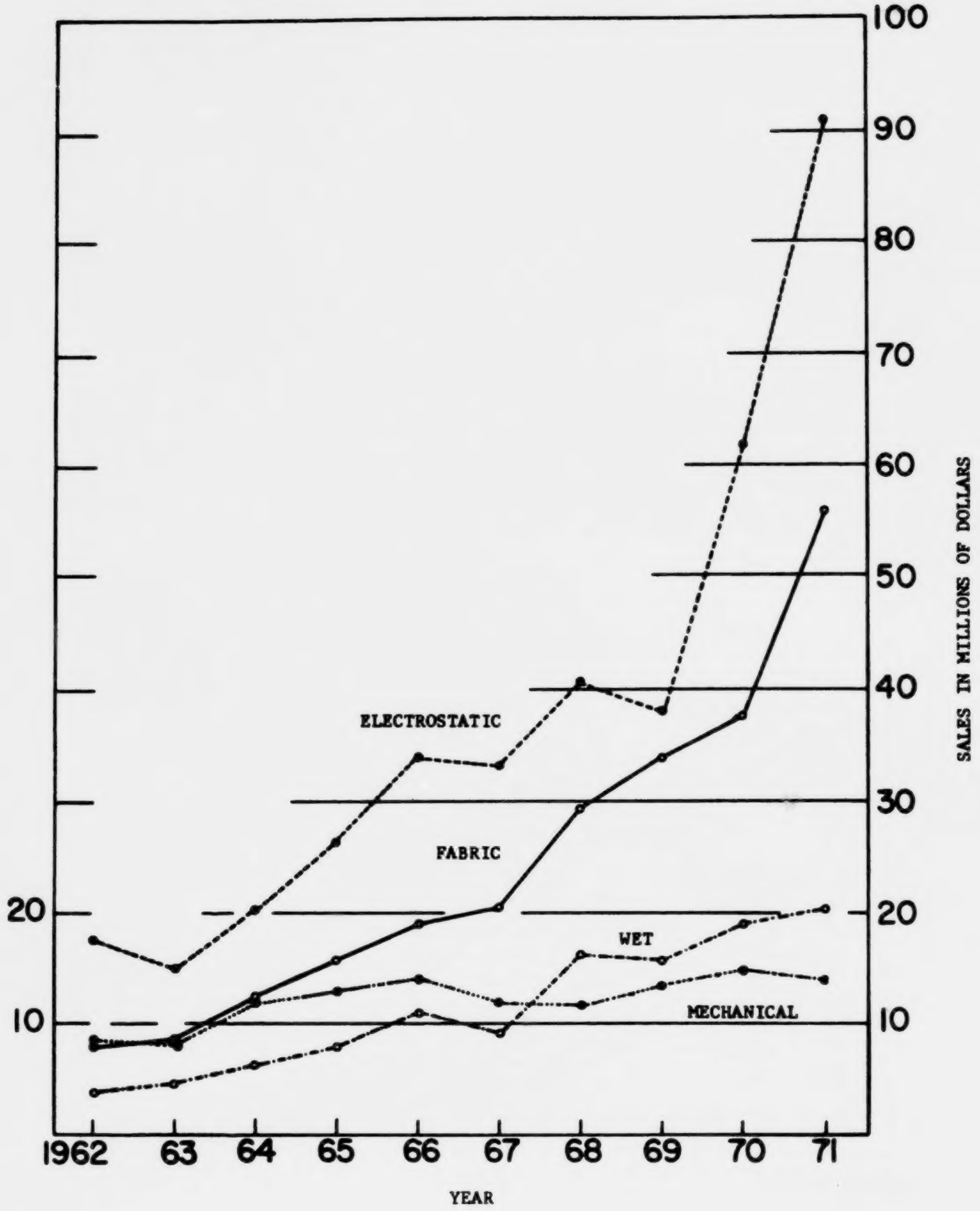

Figure 19. Control equipment sales in United States and Canada[71]

Table 26. USE OF PARTICULATE COLLECTORS BY INDUSTRY[72]

Material classification	Process	EP	FF	WS
Utilities and industrial power plants	Coal	0	--	--
	Oil	0	--	--
	Natural gas	--	--	--
	Lignite	0	--	--
	Wood and bark	+	--	+
	Bagasse	--	--	--
	Fluid coke	0	--	--
Pulp and paper	Kraft	0	--	0
	Soda	0	--	0
	Lime kiln	--	--	0
	Chemical	--	--	0
	Dissolver tank vents	--	--	--
Rock products	Cement	0	0	+
	Phosphate	0	0	0
	Gypsum	0	0	0
	Alumina	0	0	+
	Lime	0	+	--
	Bauxite	0	--	--
	Magnesium oxide	+	--	--
Steel	Blast furnace	0	--	0
	Open hearth	0	--	+
	Basic oxygen furnace	0	--	0
	Electric furnace	+	0	0
	Sintering	0	--	--
	Coke ovens	0	--	--
	Ore roasters	0	--	+
	Cupola	+	+	0
	Pyrites roaster	0	--	0
	Taconite	+	--	--
	Hot scarfing	0	--	--
Mining and metallurgical	Zinc roaster	0	--	--
	Zinc smelter	0	--	--
	Copper roaster	0	--	--
	Copper reverb	0	--	--
	Copper converter	0	--	--
	Lead furnace	--	0	0
	Aluminum	0	--	0
	Elemental Phos.	0	--	--
	Ilmenite	0	--	--
	Titanium dioxide	+	0	--
	Molybdenum	+	--	--
Miscellaneous	Municipal incineration	+	--	--

0 Most common
+ Not normally used

EP Electrostatic precipitator
FF Fabric filter
WS Wet scrubber

Zinc smelting
Lime kilns
Asphalt plant dryers
Aluminum remelt furnaces
Metallurgical operations involving
  oil and pulverized coal blends
Steel mills
Lime reburners
Brick manufacture

Some of those reporting firms have already had experience with waste oil combustion primarily in uncontrolled industrial boilers. While some have been satisfied with the results, others expressed reservations concerning maintenance, reliability of heating value and pollution, and indicated an interest only in treated and preblended fuels.

Blends with No. 6 residual were generally more successful than blends with No. 2 distillate. Use of untreated waste oil fuel in equipment designed for atomization and combustion of distillate fuels generally led to increased maintenance problems. Firms expressing an interest in process fuels such as those used to fire kilns, expressed most concern about constant heating values and possible contamination.

In summation, the efficient control of effluent emissions from utilities, industrial boilers, and certain processing operations will allow waste oil fuels to be utilized even in high blend ratios without exceeding proposed and existing ambient air quality levels for lead and particulate emissions. Control equipment is now used in many industries, and waste oil fuel blends could be utilized with low-level pretreatment and investment. The installation of control equipment for the specific purpose of reducing waste oil combustion impacts is probably not warranted except for large users such as electric utilities and large industrial boilers. However, as new source standards are promulgated, the use of control equipment will increase and extend the potential for waste oil utilization. The installation and operating costs of high efficiency control equipment is given in Section IX.

SECTION IX

ECONOMICS OF IMPACT REDUCTION ALTERNATIVES

This section presents the economics associated with the waste oil treatment and particulate control systems discussed in the previous section. The presentation will include the development of capital investment and operating costs for each impact reduction alternative. Factors will then be presented to permit the calculation of these costs for alternative capacities. The presentation of these costs, however, will be preceded by a discussion of the assumptions utilized in their development.

BASIS FOR COST ESTIMATES

Capital Equipment Costs

The data utilized to obtain purchased equipment costs were obtained both through personal communications with equipment manufacturers[47] and the use of latest published information. In all cases the capital investments are on the common basis of construction and equipment costs for the Northeastern United States, in 1973 dollars. Table 27 presents the assumptions utilized in the development of capital investment costs.

The following explains the categories listed in Table 27:

1. Equipment Installation

   The installation of equipment includes costs for labor, foundation, supports, platform, construction expenses, and other factors related to the erection of purchased equipment.

2. Piping

   The costs for piping cover labor, valves, fittings, pipe, supports, and other items involved in the complete erection of all piping used directly in the process.

3. Electrical

   The cost for electrical installation consists primarily of installation labor and materials for power and lighting, with building service lighting included under the heading of building costs.

4. Instrumentation and Controls

Instrumentation costs, installation labor costs, and expenses for auxiliary equipment and materials constitute the major portion of the capital investment required for instrumentation.

5. Buildings

The cost for buildings consists of expenses for labor, materials, and supplies involved in the erection of all buildings connected with the plant.

6. Yard Improvements

Costs for fencing, grading, roads, sidewalks, landscaping and similar items constitute the portion of capital investment included in yard improvements.

7. Service Facilities

This category includes utilities for supply steam, water, power, and fuel to the industrial process.

8. Land

The costs included under this category are the cost of the land itself and the accompanying surveys and fees.

9. Engineering and Supervision

The costs for construction design and engineering, drafting, purchasing, accounting, construction and cost engineering, travel, reproduction, communications, and home office expenses including overhead constitute the capital investment for engineering and supervision.

10. Construction Expenses

This item includes temporary construction and operation, construction tools and rentals, home office personnel located at the construction site, construction payroll, travel and living, taxes and insurance, and other construction overhead.

11. Contractor's Fee

Contractor's fee is simply the remuneration to the contractor.

12. Contingency

This category compensates for unpredictable events such as storms, floods, strikes, price changes, small design changes, error in estimation, and other unforeseen expenses.

Table 27. ASSUMPTIONS MADE IN THE DEVELOPMENT OF CAPITAL INVESTMENT COSTS[74]

Category	Assumed percentage of purchased equipment costs	
	Treatment plants	Particulate control systems
1. Equipment installation	36	
2. Piping	32	Capital Cost Derived From Literature Review
3. Electrical	20	
4. Instrumentation and controls	28	
5. Buildings	20	
6. Yard improvements	8	
7. Service facilities	Personal communication with equipment manufacturer	
8. Land	4	
9. Engineering and supervision	40	
10. Construction expense	48	
11. Contractor's fee	8	
12. Contingency	32	

Working capital is included under capital investiment for financing (1) raw materials and supplies carried in stock, (2) accounts receivable, (3) cash on hand for monthly operating expenses, (4) accounts payable, and (5) taxes payable. The ratio of working capital to total capital investment ranges from 10 to 20 percent of the total capital investment. For purposes of this study, the midrange value of 15% was utilized.

The scale factor for determining capital investment costs for varying plant capacities is 0.6 $\left[CI_{new} = CI_{old} \left(Cap_{new}/Cap_{old} \right)^{0.6} \right]$. This was developed from primary cost data developed by GCA for plants of three capacities (1 million, 7 million, and 15 million gallons per year). The empirical data used for this calculation is found in Appendix F.

Annual Operating Costs

The annual operating costs include the following fixed, variable, and semi-variable costs:

Fixed Costs -

1. Amortization of capital investment - The capital investments have been amortized over a period of 20 years. This reflects the expected lifetime of the equipment based upon discussions with the equipment manufacturer.[47,48] A straight line method, which distributes the capital investment cost uniformly over the 20-year period, has been used. Size scaling for this and all other fixed cost items should be proportional to the scale factor used for capital investment costs.

2. Interest on loan - An interest rate of 8 percent of the total capital investment was used. It was further assumed that the interest is to be paid after 1 year, but is capitalized uniformly over the estimated 20-year lifetime of the equipment. It is recognized that the necessary initial capital requirements could be raised through a variety of methods (e.g., borrowing, bond issue, etc.) at a range of finance costs. The 8 percent figure represents a reasonable estimate which can be varied according to existing money market conditions.

3. Insurance - The cost of insurance was estimated to be 0.5 percent of total capital investment. This figure is suggested by Peters and Timmerhaus[74] as a lower limit for such facilities. The range is from 0.5 to 1.0 percent.

Variable and Semi-Variable Costs -

1. Waste oil - For treatment processes, an average wholesale cost of 5 cents per gallon was assigned to waste oil. This reflects examination of the recent literature[3,5] and discussions with waste oil users.[57] The term wholesale applies to waste oil delivered directly to the treatment facility from the generating source, without intermediate storage and handling.

The cost of waste oil for systems of different sizes will vary directly with the size. The scale factor is therefore equal to 1.0.

2. Labor costs - The annual labor costs associated with the operation of the treatment and control facilities was obtained by taking the number of manhours required during the year and applying a wage rate of $10/manhour.

   For purposes of this study, a scale factor of 0.25 has been used for determining labor costs as a function of size. This factor is taken from an article by F.P. O'Connell in "Modern Cost-Engineering Techniques"[75] and is based on data gathered for 52 chemical processes.

3. Maintenance costs - An annual maintenance cost of 7 percent of the capital equipment cost was selected for this analysis. This is a high figure representative of that normally found for corrosive processes.[74] Since maintenance costs have been estimated as a percentage of equipment cost, the equipment cost scale factor should be applied to determine the cost of other size installations.

4. General and administrative costs - The costs of overhead were estimated at 40 percent of labor and supervision. This is the lower end of the 40 to 70 percent range[74] due to lack of administration staff needed.

5. Electrical costs - Electrical costs were estimated at $0.015 per kWh. Since electrical requirements will vary directly with plant capacity, it has a scale factor of 1.0. The range of electricity costs is from $0.015 to $0.030 per kWh.[81]

6. Caustic soda costs - The cost of the requisite caustic soda necessary for these treatment processes is based upon communication with producers.[31] Scale factor equals 1.0.

7. Demulsifier surfactant - The cost of the required demulsifier surfactant is based upon communication with producers.[76] Scale factor equals 1.0.

PRESENTATION OF DATA

Treatment Alternatives

The following tables present the initial capital investment and annual operating costs associated with the various treatment alternatives. The yield factors cited are based upon GCA engineering estimates of the processes.

The costs given in these tables are order of magnitude estimates. Actual costs may vary by as much as plus or minus 50 percent. Rather than give ranges for the costs discussed, the aforementioned assumptions are used. In Section X, range values are given which reflect variations in electric costs, waste oil feed prices, and the like.

Settling - As shown in Tables 28 and 29, treatment by settling involves an initial capital outlay of $1.44 million. This facility would operate 24 hours per day, 313 days per year, as would the other systems discussed below. It is estimated that this system would yield 12.75 million gallons of waste oil fuel product (85 percent of feed input). Given the annual cost, the product would cost approximately 11 cents per gallon to produce.

Table 28. CAPITAL COST ESTIMATION OF A TREATMENT FACILITY: SETTLING

Processing capacity: 15 million gallons/ year
Plant operation: 24 hours/day - 313 days/year
Process yield: 85 percent

Fixed capital investment			$1,229,480
Direct costs		$830,240	
Installed equipment costs	$673,730		
• Purchased equipment	311,910		
• Installation	112,290		
• Piping	99,810		
• Electrical	62,380		
• Instrumentation & controls	87,340		
Land and improvements	156,510		
• Buildings	62,380		
• Yard improvements	24,950		
• Service facilities	56,700		
• Land	12,480		
Indirect costs		399,240	
Engineering and supervision	124,765		
Construction expense	149,715		
Contractor's fee	24,950		
Contingency	99,810		
Working capital			216,920
Total capital investment			$1,446,400

Table 29. ESTIMATED OPERATING COST OF A TREATMENT FACILITY: SETTLING

Total capital investment (see Table 28) $1,446,400		
	Annual cost	
Fixed costs		
Amortization at 5 percent of total C.I.	$72,320	
Interest on loan (8 percent of total C.I.)[a]	5,785	
Insurance (0.5 percent of C.I.)	7,230	
Total fixed cost per year		$ 85,335
Variable and semi-variable costs		
Residual oil (20 cents per gallon)	$ 42,700	
Waste oil feed (5 cents per gallon)	750,000	
Labor (30,048 manhours at $10/manhour)	300,480	
General and administrative (40 percent of labor)	120,190	
Caustic soda	115	
Demulsifier surfactant	56,250	
Maintenance (7 percent of fixed C.I.)	80,060	
Electric power ($0.015/kWh)	1,090	
Total variable cost per year		1,356,885
Total annual cost		$1,442,220

[a] Paid in 1 year; amortized over a 20-year period.

Centrifugation - As shown in Tables 30 and 31, the initial capital outlay for a facility of this nature would be $1.35 million with an annual operating cost of $1.33 million. The amount of waste oil fuel product would be 12.75 million gallons (85 percent yield) at a processing cost of 10 cents per gallon.

Table 30. CAPITAL COST ESTIMATION OF A TREATMENT FACILITY: CENTRIFUGATION

Processing capacity: 15 million gallons/year
Plant operation: 24 hours/day -313 days/year
Process yield: 85 percent

Fixed capital investment			$1,149,805
Direct costs		$777,685	
Installed equipment costs	$627,950		
• Purchased equipment	290,715		
• Installation	104,660		
• Piping	93,030		
• Electrical	58,145		
• Instrumentation & controls	81,400		
Land and improvements	149,735		
• Buildings	58,145		
• Yard improvements	23,260		
• Service facilities	56,700		
• Land	11,630		
Indirect costs		372,120	
Engineering and supervision	116,285		
Construction expense	139,545		
Contractor's fee	23,260		
Contingency	93,030		
Working capital			202,905
Total capital investment			$1,352,710

Table 31. ESTIMATED OPERATING COST OF A TREATMENT FACILITY: CENTRIFUGATION

Total capital investment (see Table 30) $1,352,710		
	Annual cost	
Fixed costs		
Amortization at 5 percent of total C.I.	$67,635	
Interest on loan (8 percent of total C.I.)[a]	5,410	
Insurance (0.5 percent of C.I.)	6,765	
Total fixed cost per year		$ 79,810
Variable and semi-variable costs		
Residual oil (20 cents per gallon)	42,700	
Waste oil feed (5 cents per gallon)	750,000	
Labor(22,536 manhours at $10/manhour)	225,360	
General and administrative (40 percent of labor)	90,145	
Caustic soda	115	
Demulsifier surfactant	56,250	
Maintenance (7 percent of fixed C.I.)	80,485	
Electric power ($0.015/kWh)	3,820	
Total variable cost per year		1,248,875
Total annual cost		$1,328,685

[a] Paid in 1 year; amortized over a 20-year period.

Distillation - Table 32 shows a total capital investment of approximately $1.79 million for a vacuum distillation treatment facility. This technique yields an annual output of 10.5 million gallons (70 percent of feed input). As shown in Table 33, the annual operating cost associated with this technique is $1.28 million. The processing cost is 12 cents per gallon of waste oil product.

Table 32. CAPITAL COST ESTIMATE OF A TREATMENT FACILITY: VACUUM DISTILLATION

Processing capacity: 15 million gallons/year
Plant operation: 24 hours/day - 313 days/year
Process yield: 70 percent

Fixed capital investment			$1,524,320
Direct costs		$1,081,145	
Installed equipment costs	$747,855		
• Purchased equipment	346,230		
• Installation	124,640		
• Piping	110,795		
• Electrical	69,245		
• Instrumentation & controls	96,945		
Land and improvements	333,290		
• Buildings	69,240		
• Yard improvements	27,700		
• Service facilities	222,500		
• Land	13,850		
Indirect costs		443,175	
Engineering and supervision	138,492		
Construction expense	166,190		
Contractor's fee	27,698		
Contingency	110,795		
Working capital			269,000
Total capital investment			$1,793,320

Table 33. ESTIMATED OPERATING COST OF A TREATMENT FACILITY: VACUUM DISTILLATION

Total capital investment (see Table 32) $1,793,320		
	Annual cost	
Fixed costs		
Amortization at 5 percent of total C.I.	$89,665	
Interest on loan (8 percent of total C.I.)[a]	7,175	
Insurance (0.5 percent of C.I.)	8,965	
Total fixed cost per year		$ 105,805
Variable and semi-variable costs		
Residual oil (20 cents per gallon)	39,000	
Waste oil feed (5 cents per gallon)	750,000	
Labor (22,536 manhours at $10/manhour)	225,360	
General and administrative (40 percent of labor)	56,340	
Maintenance (7 percent of fixed C.I.)	106,700	
Electric power ($0.015/kWh)	1,965	
Total variable cost per year		1,179,365
Total annual cost		$1,285,170

[a] Paid in 1 year; amortized over a 20-year period.

Solvent Extraction - Tables 34 and 35 present, respectively, the initial capital investment and annual operating cost associated with solvent extraction. This process requires an outlay of $1.76 million with a $1.56 million annual operating cost. The waste oil fuel product produced by this technique is 85 percent of the feed input, or 12.75 million gallons. The process cost is 12 cents per gallon.

Table 34. CAPITAL COST ESTIMATE OF A TREATMENT FACILITY: SOLVENT EXTRACTION

Processing capacity: 15 million gallons/year
Plant operation: 24 hours/day - 313 days/year
Process yield: 85 percent

Fixed capital investment			$1,496,660
Direct costs		$1,037,340	
Installed equipment costs	$775,110		
• Purchased equipment	358,850		
• Installation	129,185		
• Piping	114,830		
• Electrical	71,770		
• Instrumentation & controls	100,475		
Land and improvements	262,230		
• Buildings	71,770		
• Yard improvements	28,705		
• Service facilities	147,400		
• Land	14,355		
Indirect costs		459,320	
Engineering and supervision	143,540		
Construction expense	172,250		
Contractor's fee	28,700		
Contingency	114,830		
Working capital			264,115
Total capital investment			$1,760,775

Table 35. ESTIMATED OPERATING COST OF A TREATMENT FACILITY: SOLVENT EXTRACTION

Total capital investment (see Table 34) $7,760,775		
	Annual cost	
Fixed costs		
Amortization at 5 percent of total C.I.	$ 88,040	
Interest on loan (8 percent of total C.I.)[a]	7,045	
Insurance (0.5 percent of C.I.)	8,805	
Total fixed cost per year		$ 103,890
Variable and semi-variable costs		
Residual oil (20 cents per gallon)	30,000	
Waste oil feed (5 cents per gallon)	750,000	
Labor (22,536 manhours at $10/manhour)	225,360	
General and administrative (40 percent of labor)	56,340	
Maintenance (7 percent of fixed C.I.)	104,765	
Naphtha (750,000 gallons at 38 cents per gallon)	285,000	
Electric power ($0.015/kWh)	12,635	
Total variable cost per year		1,464,100
Total annual cost		$1,567,990

[a] Paid in 1 year; amortized over a 20-year period.

Emission Control Devices

The following gives capital investment and annual operating costs associated with three different types of emission control devices. These costs are not intended to serve as a detailed cost guide to such devices, but are instead presented only for relative comparisons. It is impossible to provide any more specific data, as costs depend upon a myriad of variables which change with the given situation.

Electrostatic Precipitators - Tables 36 and 37 present the cost considerations involved in the erection and operation of precipitators. As with the other emission control devices discussed in this section, it is assumed that the stack flow is 1 million cubic feet per minute (cfm). This is the approximate stack flow of a large scale facility which could potentially utilize the output quantity from the pretreatment options discussed above. A precipitator of this size would cost $3.06 million with an annual operating cost of $333,020.

Table 36. ESTIMATED CAPITAL COST OF PRECIPITATORS[77]

cfm: 1,000,000		
Total capital investment		$3,062,700
Direct costs	$1,862,250	
• Purchased equipment • Erection		
Indirect costs	$1,200,450	
• Engineering and supervision • Ductwork • Air flow regulators		

Table 37. ESTIMATED OPERATING COST OF PRECIPITATORS[77]

Total capital investment (see Table 36) $3,062,700		
Fixed cost	Annual cost	
Amortization at 5 percent of total C.I.	$153,135	
Interest on loan (8 percent of total C.I.)[a]	12,250	
Insurance (1 percent of C.I.)	30,630	
Total fixed cost per year		$196,015
Variable and semi-variable costs		
Labor (675 manhours at $10/manhour)	6,750	
Maintenance (2 percent of C.I.)	61,255	
Electric power ($0.030/kWh)	69,000	
Total variable cost per year		137,005
Total annual cost		$333,020

[a] Paid in 1 year; amortized over a 20-year period.

Fabric Filtration - Table 38 shows the capital cost to be $2.88 million for a fabric filtration facility. This estimate is based upon an average cost of $2.88 per cfm suggested in the GCA study, Handbook of Fabric Filter Technology.[71] The operating cost is $1,080,910 annually[71] as seen in Table 39.

Table 38. CAPITAL COST ESTIMATE OF FABRIC FILTRATION

cfm: 1,000,000		
Total capital investment		$2,879,800
Direct costs	$1,331,000	
• Purchased equipment		
• Erection		
Indirect costs	$1,548,800	
• Engineering and supervision		
• Ductwork		

Table 39. ESTIMATED OPERATING COST FOR FABRIC FILTRATION

Total capital investment (see Table 38) $2,879,800		
	Annual cost	
Fixed cost		
Amortization at 5 percent of total C.I.	$143,990	
Interest on loa (8 percent of total C.I.)[a]	11,520	
Insurance (0.5 percent of C.I.)	14,400	
Total fixed cost per year		$169,610
Variable and semi-variable costs		
Labor ($0.30 per cfm)	300,000	
Electric power (0.030/kWh)	240,000	
Plant overheat ($0.25/cfm)	250,000	
Cloth purchases ($0.10/cfm)	121,000	
Total variable cost per year		911,000
Total annual cost		$1,080,910

[a] Paid in 1 year; amortized over a 20-year period.

High Energy Venturi Scrubber - As shown in Table 40, the estimated capital expenditure for a high energy venturi scrubber is $2.45 million. Table 41 shows the annual operating cost to be $1,356,940. Both of these estimates are based upon information presented in APT, Scrubber Handbook.[73]

Table 40. CAPITAL COST ESTIMATE OF HIGH ENERGY VENTURI SCRUBBER[73]

cfm: 1,000,000		
Total capital investment		$2,457,490
Direct costs	$1,228,745	
• Purchased equipment • Erection		
Indirect costs	$1,228,745	
• Engineering and supervision • Startup		

Table 41. ESTIMATED OPERATING COST OF HIGH ENERGY VENTURI SCRUBBER[73]

Total capital investment (see Table 40) $2,457,490		
	Annual cost	
Fixed cost		
Amortization at 5 percent of total C.I.	$122,875	
Interest on loan (8 percent of total C.I.)[a]	9,830	
Insurance (0.5 percent of C.I.)	12,290	
Total fixed cost per year		$ 144,995
Variable and semi-variable cost		
Labor and maintenance (1 percent of C.I.)	24,575	
Electric power ($0.030/kWh)	987,370	
Water ($0.50/100 cubic feet)	200,000	
Total variable cost per year		1,211,945
Total annual cost		$1,356,940

[a] Paid in 1 year; amortized over a 20-year period.

Summary of Impact Reduction Alternatives

Table 42 presents in summary fashion the capital cost and annual operating cost associated with each impact reduction alternative.

Table 42. SUMMARY TABLE ON THE ECONOMICS OF IMPACT REDUCTION ALTERNATIVES

Impact reduction alternatives	Initial capital investment (millions of $)	Annual operating cost (millions of $)
Settling	1.4	1.4
Centrifugation	1.4	1.3
Vacuum distillation	1.8	1.3
Solvent extraction	1.8	1.6
Precipitators	3.1	0.3
Fabric filtration	2.9	1.1
High energy scrubbers	2.5	1.4

EFFECT OF CAPACITY ON ECONOMICS OF IMPACT REDUCTION ALTERNATIVES

Treatment Facilities

Figure 20 provides a means of estimating the capital investment and operating cost associated with pretreatment capacities other than 15 million gallons per year. These curves are based upon the scale factor associated with each of the costs as discussed above. This table can be applied to any of the processes discussed. For example, the costs associated with a treatment facility processing 22.5 million gallons per year by settling are:

Capital investment (1.27 x $1,229,480)	$1,561,440	
Operating costs		
Fixed costs (1.27 x $85,335)	$ 108,375	
Waste oil feed (1.5 x $750,000)	1,125,000	
Labor (1.11 x 300,480)	333,530	
Overhead (1.11 x 120,190)	133,410	
Raw materials		
Caustic soda (1.5 x 115)	175	
Demulsifier surfactant (1.5 x 56,250)	84,375	
Maintenance (1.27 x $86,060)	109,300	
Total operating cost		$1,894,165

There appear to be significant economies of scale in the operation of treatment facilities. Table 43 provides the processing cost in cents per gallon for different capacities. As shown by the data, lower

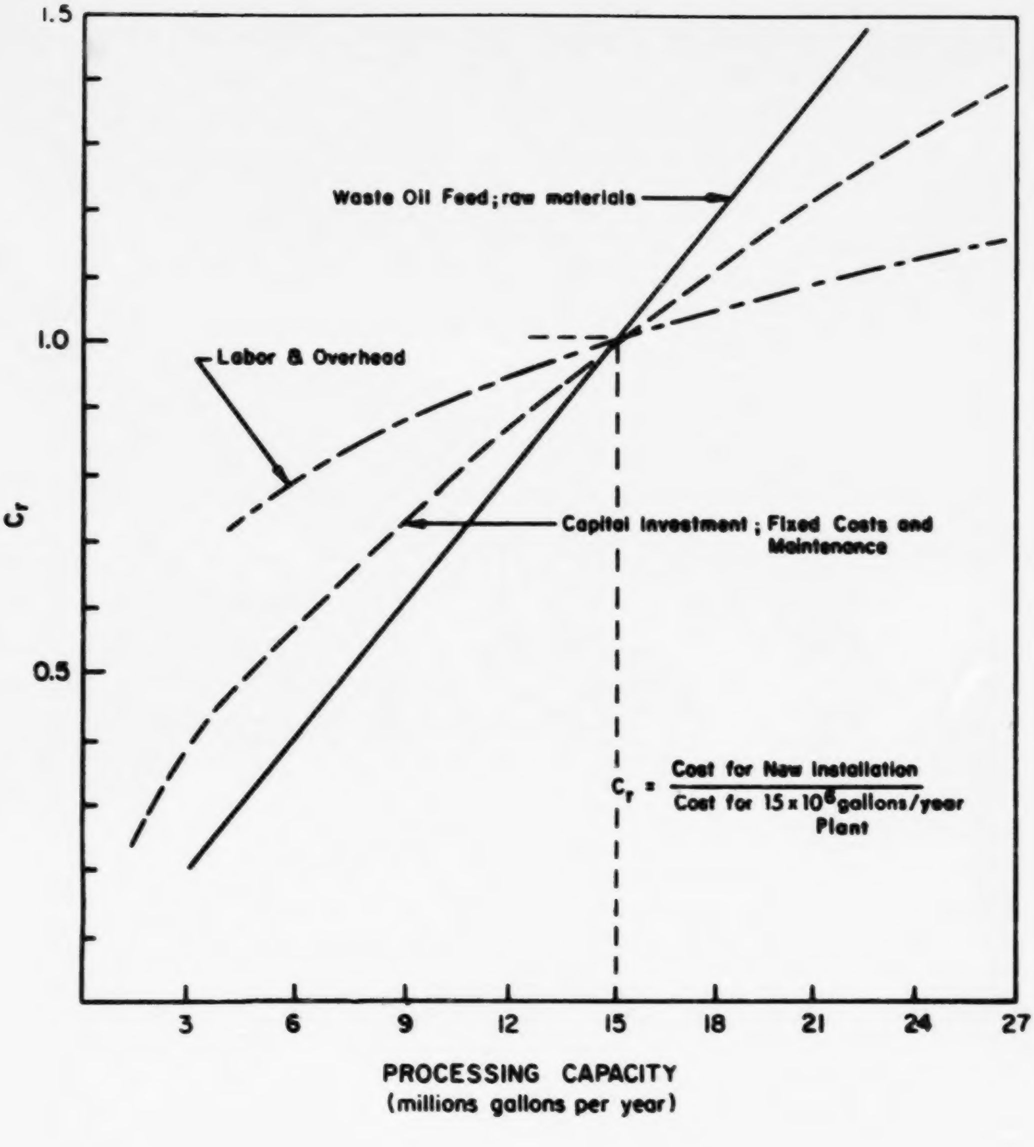

Figure 20. Investment and operating cost of pretreatment as a function of treatment facility capacity

average costs are arrived at through large scale operation.* This is one factor which would support the construction of centralized rather than decentralized facilities. Centralized facilities could achieve lower costs compared to the situation where the same aggregate amount of waste oil is processed by a number of small (< 15 millions gallons/year) treatment facilities.

Table 43. EFFECT OF CAPACITY ON PROCESSING COST
(cents per gallon)

Treatment option	Capacity (million/gallon)		
	15 gallons	7 gallons	1 gallon
Settling	11	14	23
Centrifugation	10	13	19
Vacuum distillation	12	15	23
Solvent extraction	12	15	23

Emission Control Devices

Figure 21 provides a means of estimating the capital cost and operating cost associated with control capacities other than 1,000,000 cfm. These curves are based upon the scale factor associated with each of the costs as discussed above. The use of this figure parallels that of Figure 20.

TREATMENT VERSUS EMISSION CONTROL DEVICES

It is important to note that while both treatment and emission control devices are forms of impact reduction alternatives, a simple capital cost or operating cost comparison between any specific treatment alternative and a given emission control device is not desirable. The treatment alternatives discussed are evaluated from an entrepreneurial standpoint. The data presented serves as an indicator of the processing cost involved in producing a fuel product, specifically a waste oil fuel product. The costs are those of setting up and operating a business enterprise. Emission control devices, however, represent an added expense, of both a capital cost and operating cost nature, to an ongoing business establishment unless control devices are already there. To the extent a user of waste oil would have to bear these emission control costs, the additional expense would represent a deterent to waste

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*Average processing costs are derived by dividing annual operating costs by annual throughput.

$$\left[\frac{\text{(Annual operating costs)}}{\text{(Capacity) Yield fraction)}}\right]$$

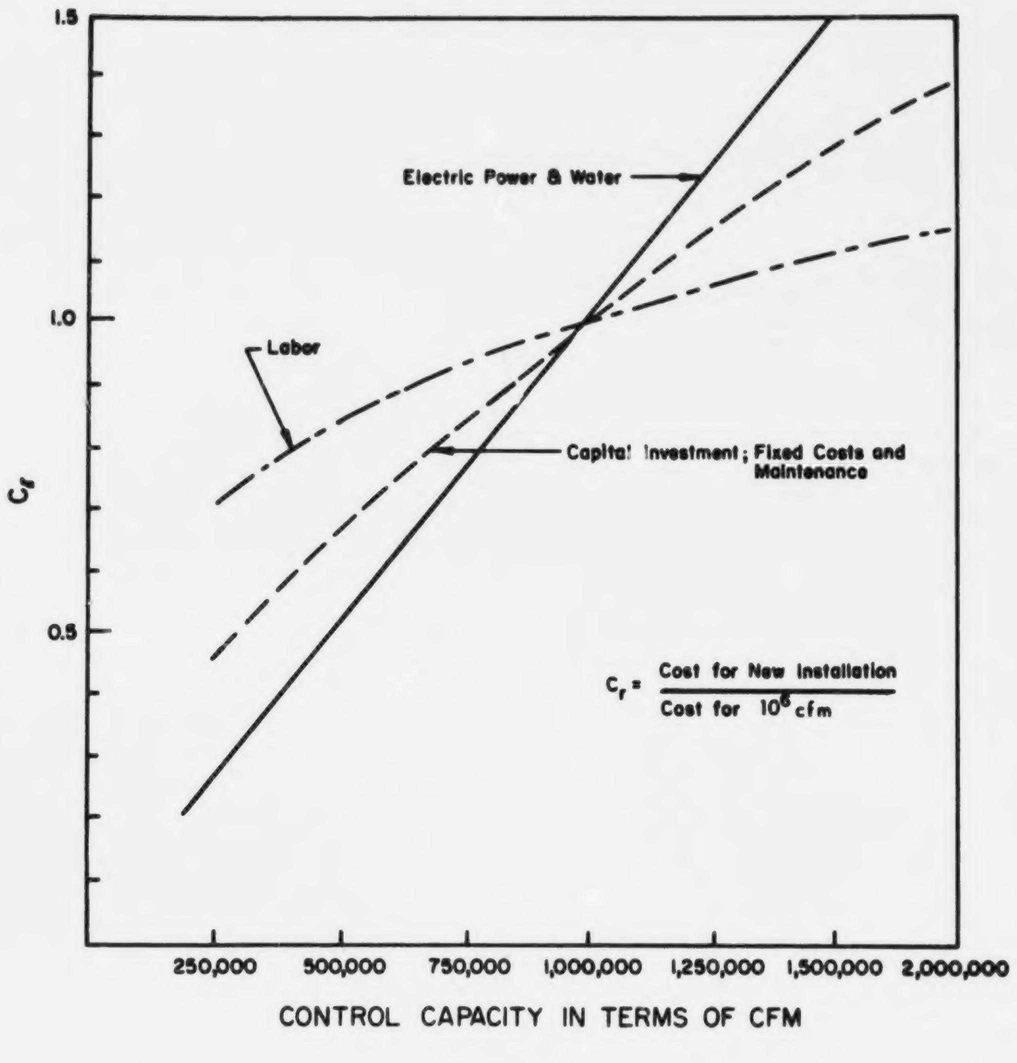

Figure 21. Investment and operating cost of particulate collection equipment as a function of control capacity

oil utilization unless these added costs are offset by fuel cost savings which arise from the lower selling price of waste oil as compared to that of virgin fuel products.

SECTION X

MARKET ANALYSES OF WASTE OIL FUELS

Section X analyzes the primary market characteristics of the waste oil fuel product and blended fuel products. The selling price of waste oil is first discussed, followed by a comparison of waste oil fuel prices with the prices of other energy sources. A qualitative discussion of supply and demand factors affecting waste oil marketability is then carried out. This analysis is based on a waste oil plant treating 15,000,000 gallons of waste oil per year.

SELLING PRICE OF TREATED WASTE OIL

The first market consideration is the selling price of waste oil. It may be safely assumed that a high selling price for the waste oil product would deter from its widespread use of an energy source. Thus far only the processing cost of waste oil has been mentioned. The additional determinants of market price are profit and distribution charges. These are discussed below.

Profit

The treatment facilities discussed in previous sections were viewed as an entrepreneurial enterprise. As such, it is imperative to include a profit margin in the selling price of the product as a return for entrepreneurial talent and effort. For purposes of this analysis, profit is assumed to be a 10-percent return on capital investment before taxes. This is consistent with both the return used in other studies[68] as well as the return experienced in similar establishments.[78] Table 44 presents the additions to selling price that reflect such a return.

Table 44. EFFECT OF PROFIT ON MARKET PRICE OF TREATED WASTE OIL

Treatment process	Annual profit (10% of capital investment)	Profit in cents/gal of product
Settling	$144,600	01
Centrifugation	135,300	01
Vacuum distillation	177,300	02
Solvent extraction	176,100	01

Distribution Costs

The distribution of waste oil product will increase the selling price by the expense associated with transporting the product to either final user or to blend facilities. Transportation costs will be the same whether the treatment facility entrepreneur owns the trucks and pays the drivers' salaries or employs the services of a trucking firm.[6]

It is estimated that the distribution of the product would add 4.5 cents per gallon to the selling price. This figure was derived by assuming that three trucks carrying 6,800 gallons each made two round trips per day. Each round trip was assumed to be 200 miles. This is enough to distribute on a daily basis the amount of product produced in a 24-hour period. A cost of $1.46 per intercity vehicle mile traveled was applied based upon an updating of recent figures on motor vehicle expense.[79] The transportation charge is simply the total vehicle expense divided by the number of gallons transported. The 4.5 cents per gallon figure appears to be compatible with other estimates of trucking costs.[6]

Price to User

The market price of the waste oil fuel product is a summation of the processing cost, profit markup, and distribution costs. A range is given for process cost. This reflects the cost of electricity going from $0.015 to $0.030 per kilowatt hour and the price of the waste oil feed varying from $0.05 to $0.08 per gallon. Table 45 presents the selling price of the waste oil product according to the treatment process employed.

Table 45. SELLING PRICE OF TREATED WASTE OIL (cents/gallon)

Treatment option	Process cost	Profit	Transport	Selling Price
Low level of treatment				
Settling	10.86-19.01	0.96	4.5	16.32-24.47
Centrifugation	10.37-18.30	0.90	4.5	15.76-23.70
High level of treatment				
Vacuum distillation	12.35-21.98	1.45	4.5	18.30-27.93
Solvent extraction	12.56-20.57	1.00	4.5	18.06-26.07

COMPARATIVE FUEL PRICES

Table 46 compares the prices of various energy sources to those of the waste oil product. While the data given are the most recent available,[80] any long run projection based upon them involves a high degree of uncertainty given the current chaos in the energy market. It does appear, however, that all levels of waste oil (high trested, low treated, and no treatment) compare favorably with other fuel oil prices. This is not true with coal prices, however. The prices given for both low treated waste oil and high treated waste oil are derived by taking the midpoint of their respective ranges, as given in Table 45 (e.g., low treated prices range from 15.76-24.47; the midpoint of this range is 20.12).

Table 46. SELLING PRICE COMPARISONS OF VIRGIN FOSSIL FUELS AND WASTE OIL FUELS

Fuel type	Gal/million BTU	Cents per gallon	Cents per million BTU
Untreated waste oil	7.19	9.0	64.71
Low treated waste oil	6.90	20.12	138.83
High treated waste oil	6.67	22.99	153.34
Residual oil	6.58	20.0	131.60
Distillate oil	7.30	26.25	191.63
Coal (greater than 3 percent sulfur)	76.92/lb	0.51/lb	39.23

Since the potential supply of the waste oil product is a small percentage of total energy demands, and given technical and environmental consideration, it may be advisable to combust a blended product. Table 47 lists the prices of various blended fuels. The blend percentages given refer to the percentage, by weight, of waste oil used. As shown by this table, as the blend percentage increases, the cost per million BTU declines with fuel oil blends while it increases with waste oil-coal blends. The blended product prices increase as the level of waste oil treatment increases.

DEMAND FACTORS AFFECTING MARKETABILITY

The selling price serves as a first indicator of successful marketability. Those factors, other than price which influence demand, will now be discussed. The most significant of these are any additional expenses that may arise from waste oil combustion. These added costs take the form of additional labor, maintenance, and equipment costs. Labor, maintenance, and equipment costs may be viewed as dependent variables with the blend percentage, blend product, treatment level, nature of uses, and volume of uses representing independent variables. The nature of the changes in these costs as they relate to the independent variables follows.

Table 47. SELLING PRICE OF BLENDED WASTE OIL PRODUCTS (cents/million BTU)[a]

Blend ratio (% waste oil by weight)	Untreated waste oil blended with			Low treated waste oil blended with			High treated waste oil blended with		
	#2	#6	Coal	#2	#6	Coal	#2	#6	Coal
0	191.63	131.60	39.23	191.63	131.60	39.23	191.63	131.60	39.23
5	184.33	124.50	40.71	186.55	133.05	46.27	187.30	133.90	47.71
50	132.00	87.00	52.32	163.15	136.40	96.29	173.97	140.47	107.26
100	64.71	74.71	64.71	138.83	138.83	138.83	153.34	153.34	153.34

[a] Calculation derived in Appendix F.

Labor Costs

- Increase as the blend percentage increases due to added equipment and maintenance requirements
- Decrease as treatment level increases
- Remain constant over different user range
- Increase as use volume increases

Maintenance (Annual Operating Cost)

- Increases as blend percentage increases
- Decrease as blend product improves
- Decreases as level of treatment increases
- Vary according to industry
- Increases as the amount used of untreated or low treated waste oil increases

Equipment (Additional Capital Investment)

- Increases as blend percentage increases based on where blending is done
- Decreases as blend product improves
- Decreases as level of treatment increases
- Varies from industry to industry depending upon existing particulate control equipment
- Increases as the amount used of untreated or low treated waste oil increases

While the nature of these cost changes can be discussed, their exact magnitude is still uncertain. User firms interviewed, as well as those responding to GCA questionnaires, mentioned added pump wear, nozzle clogging, and strainer clogging as examples of added maintenance and labor costs associated with waste oil combustion. Table 48 provides a quantification of these costs. The data given is derived from interviews with present users of waste oil as well as information obtained from questionnaires sent to past and present users. These users were combusting a waste oil product that had received only a minimum amount of pretreatment in the form of gravity settling to remove some of the bottom sediments and water. The costs given for each impact area are costs of maintenance over and above what the normal equipment maintenance costs would be.

Table 48. COSTS ASSOCIATED WITH COMBUSTION OF UNTREATED WASTE OIL[a]

Equipment maintenance	Annual cost
Overhaul of pumps	$ 1,800
Replacement of nozzle	233
Cleaning of strainers	12,000
Total annual cost of added maintenance	$14,033

[a] Only partial removal of bottom sediments and water

It is safe to assume that all of the additional maintenance costs associated with the use of waste oil have yet to be identified. As such, the above table represents only a partial listing. It reflects those areas which were common to most user cases and were quantifiable.

1. Overhaul of pumps - Untreated waste oil is extremely abrasive and tends to cause very heavy pump wear. A cost of $1,000 was assigned as the cost of a pump overhaul. It was further assumed that a pump must be overhauled every 6 months, as opposed to once every 5 years were waste oil not used. Both of these assumptions resulted from discussions with users.

2. Replacement of nozzels - Nozzels tend to wear more rapidly when waste oil is used, again due to the abrasiveness of the oil. They must be replaced on the average of every 6 months as compared to several years (average 3 years) under other fuel use conditions. Given a cost of $130 for each nozzel plus a labor fee of $10 for installation, nozzel wear involves $233 of additional cost per year for each nozzel.

3. Cleaning of strainers - Waste oil leaves significant amounts of sediment on the strainers, necessitating cleaning once each shift. This involves $20 of labor cost per shift. As a point of comparison, strainers are usually changed once a week when other sources of fuel are used.

The treatment systems discussed in Section IX (settling, centrifugation, vacuum distillation, and solvent extraction) would virtually eliminate these technical impacts. In situations where untreated waste oil is combusted, it appears desirable to blend it in small percentages (1 to 5 percent) with other energy sources. This would give rise to significantly lower maintenance and labor costs relative to higher blends.

Where untreated waste oil is combusted in high blends (25 percent or larger), any fuel cost savings might be offset by the added labor and maintenance required to overhaul pumps, unclog nozzles, and clean strainers. Such maintenance involves not only the direct costs of labor and parts, but also involves the implicit costs of equipment shutdowns and of allocation of valuable labor time to something other than that for which it was intended.

The additional capital investment or equipment costs which arise from waste oil combustion are mainly in the form of installation and operation of emission control devices. The magnitude of such costs is discussed in Section IX. The need for control equipment is eliminated when high treated waste oil is used and is significantly lessened where low treated or untreated waste oils are blended in small percentages (less than 5 percent). However, low treated or untreated waste oil in higher blend percentages would necessitate the installation of such equipment to avoid fine metal particulate emissions significantly affecting air quality. In this situation it becomes a matter of comparing the fuel cost savings (difference between waste oil price and that of other fuels) to the added equipment operating expenses.

Figure 22 shows the annual operating costs (including amortized investment) for an electrostatic precipitator of 1,000,000 actual cubic feet per minute, presumably installed at a large utility boiler or industrial facility. These costs in cents per gallon of waste oil combusted, presented in line A as a function of the annual quantities of waste oil used, are derived by dividing the annual operating cost of $333,020 (generated in Table 37 in Section IX) by the annual quantity of waste oil fired. This figure illustrates the expected phenomenon of decreasing control equipment operating costs per gallon of waste oil fired as the annual total volume of fired waste oil increases.

Also, the fuel savings per gallon of waste oil used relative to the costs of residual oil are presented for untreated waste oil (line B). The intersection of lines A and B shows that more than 3 million gallons of untreated waste oil would have to be combusted annually in order for fuel savings to offset control equipment operating costs. For untreated waste oil, however, there are additional maintenance costs as discussed above which have to be considered in an overall economic analysis.

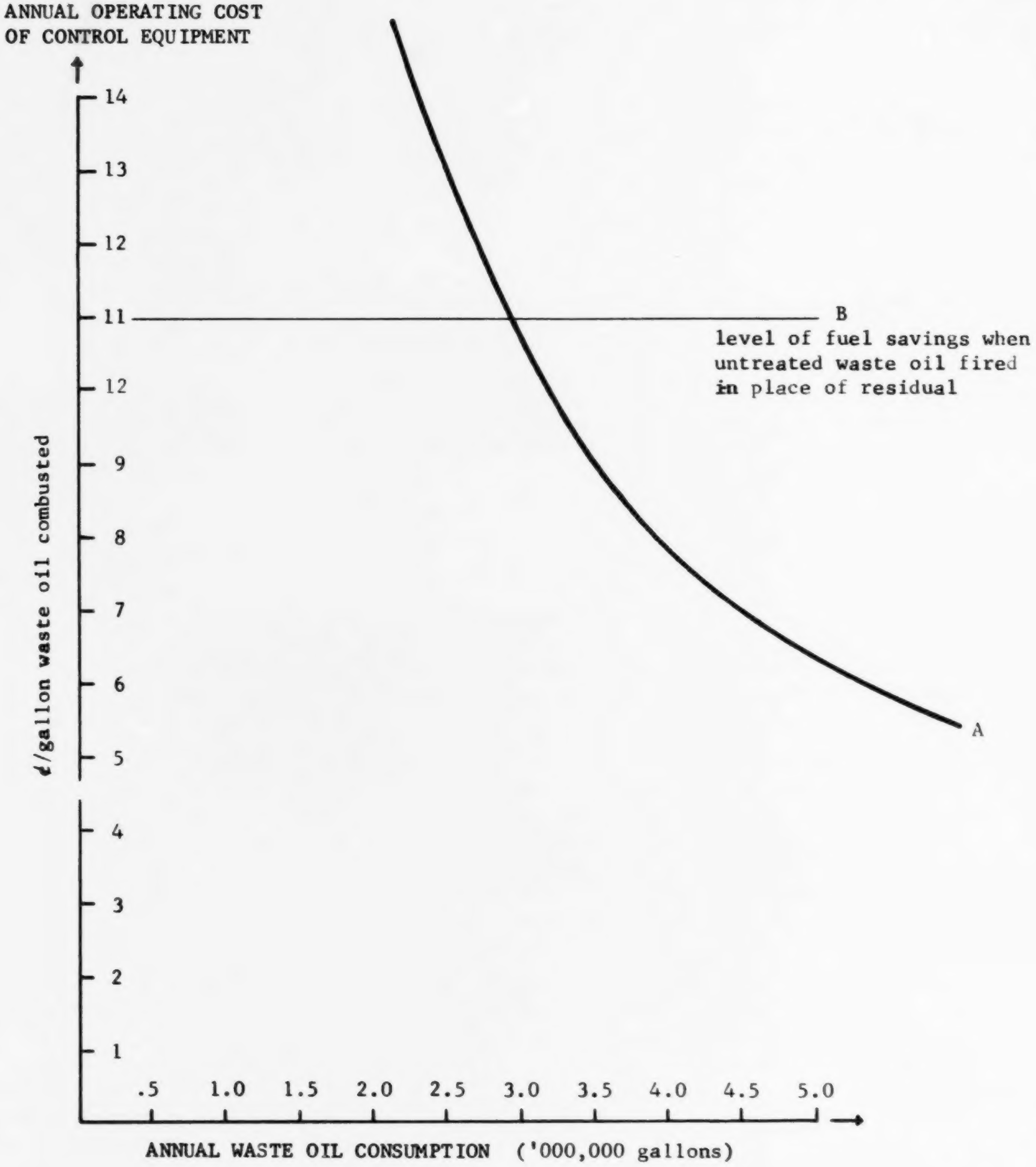

Figure 22. Comparison of fuel saving and annual control equipment operating cost

SUPPLY FACTOR AFFECTING MARKETABILITY

The supply factors which affect marketability include location of the treatment facility, the organization of the treatment facility, and the services which the pretreater provides to the user firms.

The location of treatment facilities is of prime importance. They should be near areas where there is a high degree of waste oil generation, high density population centers. At the same time, the distance between the facility and the purchasers of the product must also be taken into consideration given transportation costs.

Another consideration is how the treatment facilities are to be established. As shown, centralized facilities represent the superior option given the economies of scale present in the treatment operation. Decentralized treatment at the plant level appear feasible only in situations of extremely high use volume.

Finally, the service to be provided by the treater will also affect the marketability. Many of the respondents to the GCA questionnaires sent to potential users, cited the desirability of blending the waste oil at the supply source, and not at the user plant. Given the fact that small amounts of waste oil would be blended with large amounts of waste oil, or used with coal, it appears desirable for the waste oil product to be transported to the virgin fuel distributor, blended at these facilities, and then trucked to the user. Such a pre-blended product would add to the range of potential users.

CONCLUSION: FAVORED USE OPTIONS

The purpose of treating waste oil is to reduce environmental damage and technical impacts while at the same time adding to energy sources. Certain alternatives represent a path of least resistance in the achievement of these two goals.

1. Large users, especially utilities, could blend small percentages of a low treated or untreated waste oil with their existing energy source without necessarily adding emission control equipment.
2. Medium size users with existing emission control equipment could blend higher amounts of high treated or low treated waste oil with their other fuel sources.
3. High treated waste oil combusted by itself by a number of relatively small users.

Obviously, numerous other alternatives could present themselves given certain specific conditions. As long as a given situation involves either (1) low-blend levels or emission control equipment or (2) use of a highly treated waste oil, waste oil could be successfully used from an economic, technical, and environmental standpoint.

SECTION XI

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APPENDIX A

ESTIMATED WASTE LUBRICATING OIL ANNUAL SUPPLY BY STATE AND REGION (1971)

	Automotive (gallons)	Industrial (gallons)
New England		
Maine	3,339,070	822,170
New Hampshire	1,680,430	257,769
Vermont	1,330,400	190,565
Massachusetts	13,404,420	6,129,556
Rhode Island	1,912,560	770,858
Connecticut	6,743,770	3,652,711
	28,410,650	11,823,629
Middle Atlantic		
New York	32,016,880	15,546,678
New Jersey	18,071,960	18,459,034
Pennsylvania	35,728,740	27,823,461
	85,817,580	61,829,173
East North Central		
Ohio	36,627,970	29,795,774
Indiana	17,722,970	12,991,233
Illinois	37,263,020	26,383,747
Michigan	37,488,000	19,571,150
Wisconsin	17,262,010	5,073,985
	146,363,970	93,815,889
West North Central		
Minnesota	14,533,400	3,213,530
Iowa	11,103,710	2,400,122
Missouri	19,701,790	4,283,712
North Dakota	4,046,060	271,254
South Dakota	4,400,210	203,592
Nebraska	8,846,970	1,633,035
Kansas	14,381,400	2,979,826
	77,013,540	14,985,071

	Automotive (gallons)	Industrial (gallons)
South Atlantic		
Delaware	1,624,870	435,653
Maryland	7,286,110	3,102,488
Washington, D.C.	1,638,780	NA
Virginia	10,839,43-	3,017,776
West Virginia	6,530,830	7,432,560
North Carolina	13,832,020	4,585,158
South Carolina	6,432,670	1,678,776
Georgia	14,495,260	6,442,547
Florida	14,445,970	5,056,982
	77,125,940	31,751,940
East South Central		
Kentucky	14,075,660	639,301
Tennessee	12,665,700	10,442,178
Alabama	12,182,640	4,719,116
Mississippi	9,185,500	2,707,690
	48,109,500	18,508,285
West South Central		
Arkansas	8,008,590	3,085,107
Louisana	15,163,310	12,070,643
Oklahoma	12,295,480	4,249,737
Texas	47,222,230	32,778,546
	82,689,610	52,183,669
Mountain		
Montana	4,191,070	503,289
Idaho	3,435,230	392,549
Wyoming	2,563,700	470,723
Colorado	8,229,900	1,920,620
New Mexico	4,760,980	1,548,790
Arizona	6,358,600	1,279,087
Utah	4,647,950	1,062,643
Nevada	2,381,820	257,644
	36,569,250	7,435,345

	Automotive (gallons)	Industrial (gallons)
Pacific		
Washington	11,047,210	2,845,560
Oregon	12,020,320	2,977,082
California	72,034,320	20,021,638
Alaska	1,395,900	190,920
Hawaii	1,857,600	NA
	98,355,350	26,035,678

Total Waste Oil	998,824,069
Automotive	680,455,390
Industrial	318,368,679

Sources of Input Data in Calculation:

1. Environmental Quality Systems, Inc., Waste Oil Recovery Practices, State of the Art (1972), prepared for the Maryland Environmental Service and U.S. Environmental Protection Agency, Washington, D.C., December 1972.

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APPENDIX B

FOSSIL COAL AND OIL FUELS CONSUMED IN THE UNITED STATES BY INDUSTRIAL SECTOR IN 1971: DEMAND BY STATE AND CENSUS REGION[14]

Region and Industrial Group (SIC)[a]	Fossil Fuel Consumption 1971			
	Fuel Oil (Thousand Barrels)			Coal (Thousand Short Tons)
	Total	Distillate	Residual	
Region: New England				
20	1,957.9	754.9	1,203.1	3.9
21	---	---	---	---
22	3,081.1	909.3	2,172.1	6.3
23	40.1	30.4	9.7	---
24	92.7	61.4	31.3	---
25	107.6	33.1	74.5	11.0
26	13,464.4	1,767.8	11,696.5	27.0
27	248.7	105.8	143.0	---
28	3,114.9	548.8	2,566.1	1.5
29	---	---	---	---
30	855.9	231.6	624.4	0.8
31	679.1	212.9	466.1	1.1
32	1,952.9	730.6	1,222.2	---
33	2,076.9	782.8	1,294.2	3.9
34	1,302.8	773.8	529.0	5.4
35	1,364.5	656.7	708.0	0.4
36	1,369.6	472.5	897.0	0.5
37	1,374.7	315.0	1,059.8	---
38	526.5	220.2	306.4	---
39	1,185.6	379.4	806.3	0.1

[a] Definition of SIC code by Major Industrial Group appear at the end of this appendix.

Region and Industrial Group (SIC)	Fossil Fuel Consumption 1971			
	Fuel Oil (Thousand Barrels)			Coal (Thousand Short Tons)
	Total	Distillate	Residual	
Middle Atlantic				
20	6,857.4	3,969.1	2,888.2	323.7
21	---	---	---	---
22	2,603.9	1,111.8	1,492.2	44.4
23	599.4	507.2	92.2	9.7
24	57.7	45.2	12.6	0.7
25	267.4	189.6	77.7	25.5
26	12,439.1	5,064.7	7,374.3	1,229.7
27	509.6	370.7	138.9	0.8
28	14,137.5	7,120.4	7,017.1	2,419.1
29	5,993.4	1,129.5	4,863.9	210.5
30	1,575.8	1,028.9	546.9	115.0
31	313.7	269.6	44.2	37.2
32	3,448.5	1,744.4	1,704.1	2,284.5
33	12,274.5	4,355.6	7,918.7	2,186.7
34	1,974.6	1,121.9	843.6	48.8
35	2,301.7	1,103.8	1,197.9	115.7
36	2,459.8	1,410.8	1,049.2	123.1
37	2,072.2	1,179.5	892.7	265.3
38	955.6	140.8	814.8	671.9
39	989.9	582.1	407.9	35.4
East North Central				
20	2,697.0	1,372.5	1,324.5	2,084.6
21	---	---	---	---
22	45.5	16.9	28.6	15.3
23	33.1	16.0	17.0	20.7
24	26.5	71.1	5.4	88.0
25	192.7	88.8	103.9	72.6
26	2,198.0	1,092.2	1,106.7	4,619.6
27	314.3	246.9	67.2	16.4

Region and Industrial Group (SIC)	Fossil Fuel Consumption 1971			
	Fuel Oil (Thousand Barrels)			Coal (Thousand Short Tons)
	Total	Distillate	Residual	
East North Central (cont)				
28	2,741.3	1,250.9	1,460.3	5,256.5
29	2,698.4	304.0	2,394.2	37.5
30	724.9	412.0	312.8	1,075.0
31	120.8	68.1	52.5	11.6
32	1,359.8	882.3	425.5	4,081.9
33	12,276.5	7,201.1	5,075.4	4,474.1
34	996.5	602.3	364.3	543.7
35	2,063.0	1,024.9	494.6	884.3
36	962.2	639.9	322.3	465.3
37	1,605.0	3,224.6	639.3	2,222.1
38	137.2	113.9	23.3	23.0
39	463.6	403.9	59.7	56.2
West North Central				
20	2,118.9	1,234.9	884.1	1,243.1
21	---	---	---	---
22	17.2	16.3	0.9	0.4
23	28.1	21.8	6.3	1.5
24	48.0	37.7	7.9	15.2
25	0.4	0.4	---	0.1
26	504.2	75.9	428.3	175.0
27	50.0	49.5	0.5	0.4
28	466.4	380.1	86.3	314.4
29	111.8	101.1	10.8	---
30	81.6	186.0	58.8	1.6
31	---	---	---	---
32	467.5	167.4	300.1	1,137.7
33	775.6	157.6	618.0	10.2
34	130.7	102.6	28.0	0.8
35	180.6	125.9	54.7	134.9

Region and Industrial Group (SIC)	Fossil Fuel Consumption 1971			
	Fuel Oil (Thousand Barrels)			Coal (Thousand Short Tons)
	Total	Distillate	Residual	
West North Central (cont)				
36	101.5	99.3	2.3	---
37	136.5	38.9	97.6	58.1
38	49.1	39.5	9.7	---
39	289.9	170.7	119.2	5.1
South Atlantic				
20	3,368.0	1,733.2	1,997.4	130.8
21	538.3	105.2	433.1	154.3
22	4,920.0	2,274.0	2,646.1	1,414.6
23	187.7	159.8	28.9	109.8
24	506.7	376.3	130.4	1.8
25	182.4	133.6	48.8	109.3
26	23,333.8	6,658.8	16,675.1	2,234.1
27	68.0	33.0	35.1	---
28	9,394.3	4,244.2	5,150.1	6,524.3
29	122.5	55.6	66.9	22.7
30	775.3	575.7	199.7	13.9
31	67.3	62.0	5.3	2.3
32	4,620.4	2,652.3	1,968.2	960.1
33	4,823.6	1,197.6	3,626.2	1,057.2
34	166.7	132.0	34.6	1.7
35	255.1	109.6	145.7	0.3
36	303.4	177.2	126.2	0.2
37	802.2	215.6	586.5	39.1
38	77.4	70.1	7.3	1.7
39	42.6	40.1	2.5	6.7

Region and Industrial Group (SIC)	Fossil Fuel Consumption 1971			
	Fuel Oil (Thousand Barrels)			Coal (Thousand Short Tons)
	Total	Distillate	Residual	
East South Central				
20	356.4	221.2	135.2	315.3
21	28.7	3.6	25.1	10.5
22	305.1	243.2	61.7	61.0
23	32.8	11.8	21.1	1.7
24	112.0	100.7	11.3	2.9
25	22.3	22.3	---	3.2
26	2,823.7	1,147.0	1,676.7	1,079.8
27	5.3	0.5	4.8	---
28	685.6	404.3	281.2	3,640.9
29	30.9	10.9	20.0	---
30	247.9	243.9	4.0	32.6
31	0.2	0.2	---	7.7
32	538.9	401.3	137.6	732.9
33	1,020.5	246.5	773.9	212.1
34	61.4	47.8	13.6	47.0
35	37.0	27.9	9.1	75.1
36	109.1	83.9	25.2	96.8
37	54.3	39.2	15.1	22.2
38	0.9	0.2	0.7	---
39	13.6	2.3	11.3	0.6
West South Central				
20	193.7	136.7	56.9	---
21	---	---	---	---
22	4.6	0.5	4.1	---
23	---	---	---	---
24	95.7	92.4	3.3	---
25	0.5	0.5	---	---
26	1,832.3	477.3	1,354.9	---
27	---	---	---	---

Region and Industrial Group (SIC)	Fossil Fuel Consumption 1971			
	Fuel Oil (Thousand Barrels)			Coal (Thousand Short Tons)
	Total	Distillate	Residual	
West South Central (cont)				
28	520.6	5.5	515.2	---
29	2,512.3	1,069.0	1,443.3	---
30	1.4	1.4	---	---
31	---	---	---	---
32	1,092.3	392.3	700.1	---
33	380.0	264.0	116.0	1,172.3
34	7.6	7.6	---	---
35	8.6	7.5	1.1	---
36	7.8	7.8	---	---
37	41.7	31.7	10.0	---
38	---	---	---	---
39	26.3	26.3	---	---
Mountain[a]				
20	437.2	333.7	103.5	292.7
21	---	---	---	---
22	---	---	---	---
23	---	---	---	---
24	171.0	150.2	20.8	---
25	---	---	---	---
26	1.8	0.1	1.6	---
27	---	---	---	---
28	133.6	59.7	73.9	8.7
29	38.6	12.8	25.8	---
30	---	---	---	---
31	---	---	---	---
32	182.1	79.9	103.1	49.6
33	97.0	93.0	4.0	---
34	3.1	3.1	---	---

[a] New Mexico excluded as no SIU breakdown given. Totals for New Mexico are: 33.0 17.2 15.9 ---

Region and Industrial Group (SIC)	Fossil Fuel Consumption 1971			
	Fuel Oil (Thousand Barrels)			Coal (Thousand Short Tons)
	Total	Distillate	Residual	
Mountain (cont)				
35	16.9	16.9	---	---
36	1.0	1.0	---	---
37	105.1	105.1	---	2.9
38	---	---	---	---
39	---	---	---	---
Pacific				
20	2,061.5	1,014.2	1,047.3	46.4
21	---	---	---	---
22	0.2	0.2	---	---
23	123.3	123.3	---	---
24	2,167.7	1,829.7	338.1	4.4
25	0.1	0.1	---	---
26	5,611.2	1,157.7	4,453.7	6.5
27	0.3	0.3	---	---
28	721.0	340.3	380.7	30.8
29	234.8	91.4	143.4	---
30	34.0	28.5	5.5	0.8
31	---	---	---	---
32	1,015.8	435.9	579.9	0.8
33	1,373.5	1,032.5	341.0	3.6
34	96.3	46.2	50.1	---
35	107.7	33.7	74.0	1.7
36	45.7	10.8	34.9	---
37	256.3	215.9	40.4	---
38	0.7	0.7	---	---
39	0.9	0.9	---	---

Source: U.S. Department of Commerce, Bureau of the Census, 1972 Census of Manufacturers: Fuels and Electrical Energy Consumed, Special Report Series, Washington, D.C.: U.S. Government Printing Office, July 1973.

SIC Code Definitions

SIC Code	Major Industrial Group (SIC)
20	Food and kindred products
21	Tobacco manufacturers
22	Textile mill products
23	Apparel and related products
24	Lumber and wood products
25	Furniture and Fixtures
26	Paper and allied products
27	Printing and publishing
28	Chemicals and allied products
29	Petroleum and coal products
30	Rubber and plastics products
31	Leather and leather products
32	Stone, clay, and glass products
33	Primary metal industries
34	Fabricated metal products
35	Machinery, except electrical
36	Electrical machinery
37	Transportation equipment
38	Instruments and related products
39	Miscellaneous manufacturing

APPENDIX C

WASTE OIL FUEL USE QUESTIONNAIRE DISTRIBUTED TO COAL AND OIL FUELED STEAM-ELECTRIC UTILITIES IN THE UNITED STATES

The following information outline reports on the distribution and response data of a waste oil fuel use questionnaire distributed to a cross-section of steam-electric utilities in the United States. A copy of the questionnaire and cover letter distributed are included at the end of this Appendix.

I. GENERAL INFORMATION:

- Universe of coal and oil fueled steam-electric utilities in the United States: approximately 600 (each utility may have multiple power plant locations)

  Reference sources for utility identification:

  - Electrical World, Directory of Electrical Utilities, 1971-72, 80th Edition, New York: McGraw Hill, 1971.
  - National Coal Association, Steam-Electric Plant Factors, 1970.
- Questionnaire Distribution: 205 distributed to utilities covering all 50 states
- Questionnaire Responses: Total returns: 74 returns (35.1%)
  Valid returns: 68 returns (33.2%)

II. FEASIBILITY OF WASTE OIL USE AS A BLENDED FUEL: QUESTIONNAIRE RESPONSES

A. Believe vehicle waste oil may be combusted at their facility: 49 YES 19 NO

B. Form waste oil would be combusted:

1. Blended with fuel oil: 39 responses
2. Sprayed or mixed with coal: 15 responses
3. Other: 3-alternate applications with coal

C. Suggested pretreatment or composition/property changes listed as required to make untreated waste oil reusable as a fuel:

- filtering (7 responses)
- reduce BS&W (22 responses)
- reduce lead content (12 responses)
- reduce percent ash (7 responses)
- reduce metallic and other constituents: vanadium (3), calcium (3), iron (3), zinc (4), barium (2), phosphorous (1)

D. Maximum price firm willing to pay for:

1. Untreated waste crankcase oil: (20 responses)
    - Range values: 0-15 cents/gallon
    - Average value: 7.1 cents/gallon
2. Pretreated waste oil to specifications provided by respondent: (20 responses)
    - Range values: 0-15 cents/gallon
    - Average value: 8.3 cents/gallon

E. Quantity of waste oil fuel utility might use on a daily basis: (34 responses)

- Range values: 250-100,000 gallons/day
- Average value: 19,000 gallons/day

III. GENERAL COMMENTS

Summary of major comment:

- Power plant is presently, or has in the past, combusted waste oil as a fuel (both industrial and vehicular waste oil) -- 6 responses
- Recommended mixing ratios for waste oil with virgin coal and oil fuels:
    - 1 part in 1,000 parts virgin oil -- 1 response

  - 1 part in 100 parts virgin oil or slightly greater -- 3 responses
  - 1 pound waste oil to 1 ton of coal -- 1 response
- Cost comments
  - Need large quantities of untreated waste oil to justify handling....it is therefore better for independent supplies to do pretreatment -- 4 responses
  - Handling and testing expenses reduce the value of waste oil fuels -- 1 response
  - Cost of waste oil would have to be 10-20 percent lower than alternatives to cover increased capital and operating costs -- 1 response
  - Magnitude of additional maintenance cost very important and requires careful analysis -- 4 responses
  - Willing to pay 90-95% of market price for residual oil -- 2 responses
- Other comments
  - Waste oil may damage rubber coal feeding belts in combustion chamber -- 1 response
  - Need to investigate possibility of spontaneous combustion if oil is added in coal bunkers or pulverizers -- 2 responses
  - Recommend using waste oil fuels at utilities presently burning solid wastes -- 1 response

In order to analysis operating characteristics of the steam-electric utilities responding to the questionnaire, detailed information was obtained from the Federal Power Commission files in Washington, D.C. Electric power plant questionnaire data was analyzed from Federal Power Commission Form 67, titled "Steam-Electric Plant Air and Water Quality Control Data for the Year Ended December 31, 1972." This information was examined for 38 of the 68 utilities returning valid waste oil fuel use questionnaires, representing 69 fossil-fueled power plant locations. This cross-sectional sample was analyzed to determine whether any trends in operating characteristics existed for the respondents. Selected operating data from the Federal Power Commission revealed the following:

- Fossil fuel type presently used:
  - Coal -- 36 power plants
  - Oil (all grades) -- 51 power plants
- Air pollution emission control equipment employed at power plants
  1. Mechanical Separators -- 19 power plants
     Emission reduction efficiency:
     - Range: 65-94%
     - Average: 81.4%
  2. Electrostatic or Combination Mechanical-Electrical Precipitators -- 30 power plants
     - Range: 85-99.9%
     - Average: 93.7%

Thus the operating characteristics of the steam-electric utilities responding to the waste oil questionnaire show that both coal and oil burning operators feel that waste oil may serve as a supplemental fuel. In addition, power plants appear to have air pollution emission control equipment to reduce potential particulate matter emission, thereby influencing the possible degree of pretreatment of waste oil required prior to combustion in order to attain an environmentally acceptable fuel.

GCA TECHNOLOGY DIVISION
A Division of GCA Corporation
Bedford, Massachusetts 01730 Telephone 617-275-9000

12 October 1973

Gentlemen:

GCA Technology Division, under U.S. Environmental Protection Agency contract, is investigating the potential reuse of waste oil as a blended fuel oil. Emphasis is being placed on evaluating the technical, economic and environmental factors affecting waste oil reuse by steam-electric power facilities, but the potential use in other industrial processes is also being investigated.

At the present time several industrial firms, including electric utilities, are using, or testing for use, waste oil as a blended fuel oil, mixing it with heavy petroleum fuel oil or spraying it over coal. In the electrical power industry, for example, Hawaiian Electric is burning used crankcase and other waste oils on a routine basis, blending it from 3 to 10 parts untreated waste oil to 100 parts fuel oil. Northern States Power (NSP), in Minnesota, recently completed testing of crankcase oil as a fuel, burning it with coal in power plant operations. Test results are presently being evaluated for final decision on whether waste oil will be used on a regular basis at NSP.

These two examples serve to illustrate why optimism exists on using waste oil fuels as a means of conserving fuel resources and reducing an environmental hazard. Principal concern, however, about burning waste oil fuel blends arise from two major sources: 1) combustion equipment effects and thus maintenance costs, and 2) air pollution potentials from ash, lead and other waste oil constituents.

GCA requests your assistance in evaluating the potential use of waste oil as a blended fuel oil by providing information sought on the enclosed questionnaire. To assist in your evaluation of waste oil use, a brief description of waste crankcase oil is attached to the enclosed questionnaire.

Your timely assistance in this waste oil study is greatly appreciated and strict confidentiality will be maintained. We believe that a united effort in evaluating waste lubricating oil will enhance efforts to reduce environmental impacts of disposal, and may provide an additional fuel resource to meet energy demands. Study results will be provided to personnel of the Edison Electric Institute, who have been consulted on the questionnaire development and program approach.

Sincerely,

James W. Carroll

James W. Carroll
Senior Economist

Enclosure:
JWC:jed

GCA
CORPORATION

STEAM-ELECTRIC UTILITIES' QUESTIONNAIRE ON POTENTIAL WASTE OIL FUEL USE

Return to: James W. Carroll
GCA Technology Division
Bedford, Massachusetts 01730

I. GENERAL INFORMATION

A. Company Name ____________________

Company Address ____________________

City ____________ State ____________ Zip Code ______

B. Person Completing Form ____________________

Position (Title) ____________ Telephone ____________

II. FEASIBILITY OF WASTE OIL USE AS A BLENDED FUEL OIL

A. Based on the attached waste crankcase oil description, do you believe this type of oil may be combusted at your facilities?

____________ (YES or NO)

B. If you feel waste crankcase oil can be used, in what form would you use it? (Check the appropriate categories)

1. Blended with fuel oil ____________
2. Sprayed or mixed with coal ____________
3. Other (Specify) ____________

C. If waste oil could not be used in its present or untreated form, what pretreatment or composition/property changes would be required to make it usable? (See attached waste oil characterization)

Changes necessary: ____________________

____

____

D. What would be the maximum price your firm would be willing to pay for:

1. Untreated waste crankcase oil? ____________ CENTS/GALLON
2. Pretreated to the above listed specifications (Part C above) ____________ CENTS/GALLON

E. What quantity of waste oil fuels (approximate) might your firm use on a daily basis, to be blended with existing fuel oils, or burned with coal fuels?

____________ GALLONS/day

OMB Clearance Number 158-S73013

III. GENERAL COMMENTS: Please answer this question within the following framework: 1) Other uses of waste oil within your firm which may have been overlooked by this questionnaire (including amounts of waste oil that could be used in each instance); 2) difficulties that might be encountered in the use of waste oil which might make it too costly (increase maintenance cost, for example), or impossible to use in your firm; and 3) any other comments which you think may be of use to us.

OMB Clearance Number 158-S73013

WASTE CRANKCASE LUBRICATING OIL COMPOSITION[*]

Variable	Range of values found in literature
Gravity, °API	22.0 - 30.8
Viscosity, 100°F, SUS	130 - 753 (Average 260)
Viscosity, 210°F, SUS	33 - 61
Flash Point °F	170 - 400 °F
Pour Point	≤ -30
Water, Volume %	1 - 11 %
BS & W, Volume % (Bottom sediments and water)	2.4 - 18 %
Ash, Weight %	1.57 - 3.58 %
Heating Value, BTU/lb.	15,000 - 20,000 BTU/lb.
Sulfur, Weight %	.21 - .48 %
Lead, Weight %	.50 - 1.12 %
Calcium, Weight %	.09 - .17 %
Zinc, Weight %	.08 % (560-1610 ppm)
Phosphorous, Weight %	.05 .09 %
Barium, ppm[**]	10 - 900 ppm
Iron	95 - 800 ppm
Vanadium	< 5 ppm

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[*] Waste crankcase oil, untreated

[**] ppm = parts per million

APPENDIX D

WASTE OIL FUEL USE QUESTIONNAIRE DISTRIBUTED TO SELECTED INDUSTRIAL PROCESSES IN THE UNITED STATES

The following information outline reports on the distribution and response data of a waste oil fuel use questionnaire distributed to selected industrial firms in the United States. A copy of the questionnaire and cover letter distributed are included at the end of this Appendix.

I. GENERAL INFORMATION

- Criteria for selecting potential industrial users of waste oil, as outlined in Section IV, was based on the following:
    - Present fossil fuel energy consumption levels
    - Air pollution emission control technology employed by various industries, focusing on control of fine particles
    - Present trends in waste oil fuel usages and combustion testing at selected industries.

Table D-1 provides a summary of the industrial process categories selected for surveying, the universe of firms in each category located in the United States and the number selected for questionnaire survey.* From Table D-1, it can be seen that from a total industrial firm universe of 2668, 562 were selected for questionnaire survey. From this survey distribution, 53 questionnaire responses were received.

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*The universe of firms and distribution list for survey were obtained from the following references:

1. Dun and Bradstreet, Million Dollar Directory, 1973, New York City, New York, 1972.
2. Dun and Bradstreet, Middle Market Directory, 1973, New York City, New York, 1972.

TABLE D-1: POTENTIAL INDUSTRIAL FIRM USERS OF WASTE OIL FUELS SELECTED FOR SURVEY

Industrial Type	SIC Number	Number of Firms in the U.S.	Number of Firms surveyed
Saw and Planing Mills	2421	416	20
Pulp Mills	2611	29	15
Paper Mills	2621	126	25
Paperboard Mills	2631	71	20
Alkalis and Chlorine	2812	10	10
Cyclic Intermediates and Crudes	2815	38	11
Inorganic Pigments	2816	36	13
Industrial Organic Chemicals	2818	145	22
Industrial Organic Chemicals	2819	188	17
Plastic Materials and Resins	2812	207	19
Cellulose Manmade Fibers	2823	12	8
Organic Fibers, non-cellulose	2824	16	5
Medicinals and Botanicals	2833	52	9
Pharmaceutical Preparations	2834	183	11
Asphalt Batching	2951	142	20
Flat Glass	3211	17	5
Cement (hydraulic)	3241	49	47
Brick and Structural Clay	3251	106	10
Concrete Block and Brick	3271	171	10
Ready-mined Concrete	3273	346	15
Lime	3274	26	24
Gypsum Products	3275	13	10
Blast Furnace and Steelworks	3312	129	120
Primary Copper Smelting & Refining	3331	12	12
Primary Lead Smelting & Refining	3332	12	10
Primary Zinc Smelting & Refining	3333	11	10
Primary Aluminum Smelting & Refining	3334	15	10
Primary Non-Ferrous Smelting & Refining	3339	36	10
Secondary Non-Ferrous Smelting & Refining	3341	64	41
TOTAL NUMBER OF FIRMS		2668	562

II. PRESENT FUEL USE AND COMBUSTION EQUIPMENT CHARACTERISTICS

A. Types of fuels presently used:

- Oil (residual and distillate) -- 22 responses
- Coal (all types) -- 9 responses
- Natural gas -- 26 responses

B. Fuel oil characteristics

1. Grade of fuel oil used
   - Distillate (#2): 6 responses
   - Residual (#6): 14 responses
2. Specific gravity: Distillate: 32.0-35.0°API
   Residual: 12.7-26.0°API
3. Viscosity: Distillate: 34.0-35.0 SUS at 120°F
   Residual: 52.0-254.0 SUS at 122°F
4. Flash point: Distillate: 130-180°F
   Residual: 150-230°F
5. Ash content, weight %: Distillate: .002-.005%
   Residual: .05-.09%
6. Sulfur content, weight %: Distillate: .03-.36%
   Residual: 1.0-2.8%

C. Coal fuel characteristics

1. Ranking of coal: bituminous -- 9 responses
2. Ash content, weight %: 6.2-18.0%
3. Sulfur content, weight %: 2.0-5.0%
4. Heating value (average BTU/lb.): 12,200-13,400 BTU/lb.

D. Combustion equipment/process characteristics

1. Fuel oil combustion: Atomizing burner description:
   a. Steam used to atomize fuel: Yes -- 12 responses
   b. Air used to atomize fuel: Yes -- 13 responses

c. Oil viscosity range equipment can accommodate: 35-200 SUS at varying °F

d. Particle size sensitivity of equipment: .008-.052 inches

e. Use of fuel additives to prevent slag formation on combustion equipment: Yes: 4 responses
No: 21 responses

2. Coal combustion:

a. Coal burned with a supplementary liquid fuel:
Yes: 1 response
No: 11 responses

b. Liquid fuel used: Residual (#6)

c. Combustion equipment processes can be modified to burn liquid fuel supplement with coal: Yes: 8 responses
No: 1 response

3. Air pollution control devices presently employed on process(es):

a. Electrostatic precipitators: 11 responses

b. Cyclones: 14 responses

c. Scrubbers: 6 responses

d. Fabric filter baghouses: 9 responses

e. Other: Afterburners - 1 response

III. GOVERNMENT REGULATIONS ON PROCESS OPERATIONS

A. Fuel input regulations

1. Regulations exist on fuel specifications: Yes: 16 responses
No: 9 responses

2. Regulations specified for:

a. Sulfur limitations in fuel: .5% - 2.9%

b. Ash content limitations: .02 grains/SCF

c. Flash point limits: 200-235°F

B. Process emission standards governing firm's operation:

1. Particulate matter: Range: .1-.4 lb/million BTU

2. Sulfur oxides: Range: .55-3.0 lb/million BTU

3. Lead: Range: .5 mg/m^3 - 1.0 mg/m^3

C. Ambient air quality standards governing firm's operation:

1. Particulate matter: Range: 550-600 $\mu g/m^3$

2. Sulfur oxides: Range: 57-80 $\mu g/m^3$

3. Lead: 5 $\mu g/m^3$

IV. FEASIBILITY OF WASTE OIL USE AS A BLENDED FUEL

A. Believe vehicle waste oil may be combusted at their facility:
Yes: 17 responses
No: 14 responses

B. Form waste oil would be combusted:

1. Blended with fuel oil: 7 responses

2. Sprayed or mixed with coal: 2 responses

3. Other: Use unblended: 1 response

C. Suggested pretreatment or composition/property changes listed as required to make untreated waste oil reusable as a fuel:

- Remove BS&W (7 responses)
- Remove lead (3 responses)
- Improve viscosity (2 responses)
- Remove vanadium (1 response)
- Blend at supply source (1 response)

D. Maximum price firm willing to pay for:

1. Untreated waste crankcase: 9 responses
    - Range values: 0-10 cents/gallon
    - Average value: 5.3 cents/gallon

2. Pretreated waste oil to specifications provided by respondent: 5 responses

   - Range values: 2-20 cents/gallon
   - Average value: 13 cents/gallon

E. Quantity of waste oil fuel firm might use on a daily basis: 11 responses

- Range values: 250-200,000 gallons/day
- Average value: 32,900 gallons/day

V. GENERAL COMMENTS

Summary of major comments:

- Previous users of waste oil complained about: 1) added maintenance costs, and 2) consistency of supply
- Several respondents felt waste oil would be used only if supplies of alternatives were absent
- Those who expressed interest in waste oil fuel use expressed concern about: 1) added capital expenditures, 2) added maintenance costs, 3) consistency of supply, and 4) quality of fuel product.
- Several firms suggested that waste oil fuel be blended at fuel supply dealer level.

GCA/TECHNOLOGY DIVISION

15 October 1973

Gentlemen:

GCA Technology Division, under U.S. Environmental Protection Agency contract, is investigating the potential reuse of waste oil as a blended fuel. Emphasis is being placed on the economic, technical, and environmental factors affecting waste oil reuse in industrial combustion processes.

One example of industrial utilization of waste oil is the Allied Chemical Company. Their Solvay, New York plant consumes over 1 million gallons of waste automotive lubricants a year. The corporation buys its waste oil from independent dealers who collect it from gas stations and garages. The oil is mixed with pulverized coal and burned to produce the heat the firm needs or sprayed on the coal piles to keep the dust down.

Waste oil utilization as a blended fuel is a means of conserving fuel resources and reducing any enironmental hazards that are created by alternate means of disposal. Principal concern, however, about burning waste oil arise from two major sources: 1) combustion equipment effects and thus maintenance costs, and 2) air pollution potentials from ash, lead and other waste oil constituents.

GCA requests your assistance in evaluating the potential use of waste oil as a blended fuel by providing information on the following factors related to your firm's operation, as listed on the enclosed questionnaire: present fuel use characteristics and equipment specifications; relevant regulations/restrictions on your plant operation; and an overall assessment of waste oil use potential. To assist you in your evaluation of waste oil use, a brief description of waste crankcase oil is attached to the enclosed questionnaire.

Your timely assistance in this waste oil study is greatly appreciated and strict confidentiality will be maintained. We believe that a united effort in evaluating waste lubricating oil will enhance efforts to reduce environmental impacts of disposal, and may provide an additional fuel resource to meet energy demands. If you have any questions, please contact me.

Sincerely,

James Sahagian

James Sahagian

JS/ck
Encl.

BURLINGTON ROAD, BEDFORD, MASSACHUSETTS 01730 / PHONE: 617-275-9000

QUESTIONNAIRE ON POTENTIAL WASTE OIL FUEL USE

Return to: James Sahagian
GCA Technology Division
Bedford, Massachusetts 01730

I. GENERAL INFORMATION

A. Company Name ________________________________

Company Address ________________________________

City ______________ State __________ Zip Code ________

B. Person Completing Form ________________________________

Position (Title) ______________ Telephone ______________

INSTRUCTIONS: Please answer those questions that apply to your firm's operation, and for which data are available.

II. PRESENT FUEL USE AND COMBUSTION EQUIPMENT CHARACTERISTICS

A. Type of fuel(s) presently used by your firm:

Type	Check if used	Quantity per day used
Oil (residual and distillate)	______________	______________
Coal (all types)	______________	______________
Natural Gas	______________	______________

B. Fuel Oil Characteristics (IF APPLICABLE)

1. Grade of fuel oil used (eg. #2,4,5, or 6) ______________
2. Specific gravity ______________ °API at ______________ °F
3. Viscosity ______________ SUS at ______________ °F
4. Flash point (Closed cup) ______________ °F
5. Ash content, Weight % ______________ %
6. Sulfur content, Weight % ______________ %
7. Other specifications ________________________________

____

C. Coal Fuel Characteristics

1. Rank of coal(eg. anthracite, bituminous)____________________

2. Ash content, weight %____________________%

3. Sulfur content, weight %____________________%

4. Heating value (average) BTU/lb.____________________BTU/lb.

D. Combustion equipment/process characteristics

1. Fuel oil combustion: Atomizing burner description:

a. Is steam used to atomize the fuel?______________

b. Is air used to atomize the fuel oil?______________

c. Oil viscosity range
equipment can accomodate____________SUS at ________ F

d. Particle size sensitivity of equipment (nozzles, atomizers), i.e., what size or diameter of particles in the oil will cause fouling? ____________________

e. Are fuel additives used to prevent slag formation and deposition on tubes and hearths of heating furnances or boilers?(YES/NO)

__________, if yes, what additives are used______________

____

2. Coal combustion:

a. Is coal burned with a supplementary liquid fuel?__________
If so, what is the liquid fuel used?______________

b. Can the combustion process(es) be modified to burn liquid
fuel supplement with the coal?____________________

3. Air Pollution control devices: Does your process (es) employ any of the following emission control devices on combustion equipment stack gases.

Equipment	Check if applicable
a. Electrostatic precipitators	______________
b. Cyclones	______________
c. Scrubbers	______________
d. Fabric Filter baghouses	______________
e. Other (Specify)______________	______________

4. Process plant stack information: Briefly describe the approximate stack information relating to your process:

Stack number (number them 1, 2, 3, etc.)	Stack Height	Exit Gas characteristics		
		Temp. (°F)	Velocity	Flow rate
	ft.		FPS	CFM

III. GOVERNMENT REGULATIONS ON PROCESS OPERATIONS

A. Fuel Input Regulations

1. Do regulations exist on fuel specifications for your process facilities?______________, if so, what do these regulations govern?____

2. What regulations hold for:

    a. Sulfur limitations in fuel oil?______________________

    b. Ash content limitations in fuel?______________________

    c. Flash point limits?______________________

    d. Other restrictions?(Specify)______________________

B. Process emission standards: What are the current emission standards for the following pollutants applicable to your operations?

1. Particluate matter ______________________

2. Sulfur oxides______________________

3. Lead______________________

4. Others (Specify)______________________

C. Ambient air quality standards: What are the current standards applicable to your firm's geographic region?

1. Particulate matter______________

2. Sulfur oxides______________

3. Lead______________

4. Others (Specify)

____

____

____

D. Other process operating restrictions and environmental control regulations affecting fuel usage: Describe briefly

____

____

____

IV. FEASIBILITY OF WASTE OIL USE AS A BLENDED FUEL

A. Based on the attached waste crankcase oil description, do you believe this type of oil may be combusted at you facilities?

________________________ (YES or NO)

B. If you feel waste crankcase oil can be used, in what form would you use it? (Check the appropriate categories)

1. Blended with fuel oil ____________________

2. Sprayed or mixed with coal____________________

3. Other (Specify)__________________________

C. If waste oil could not be used in its present or untreated form, what pretreatment or composition/property changes would be required to make it usable? (See attached waste oil characterization)

Changes necessary:____

____

____

D. What would be the maximum price your firm would be willing to pay for:

1. Untreated waste crankcase oil? ________________CENTS/GALLON

2. Pretreated to the above listed specifications
   (Part C above) ____________________________CENTS/GALLON

E. What quantity of waste oil fuels (approximate) might your firm use on a daily basis, to be blended with existing fuel oils, or burned with coal fuels?

__________________________GALLONS/day

V. GENERAL COMMENTS: Please answer this question within the following framework: 1) Other uses of waste oil within your firm which may have been overlooked by this questionnaire (including amounts of waste oil that could be used in each instance); 2) difficulties that might be encountered in the use of waste oil which might make it too costly (increase maintenance cost, for example), or impossible to use in your firm; and 3) any other comments which you think may be of use to us.

OMB Clearance Number 158-S73013

WASTE CRANKCASE LUBRICATING OIL COMPOSITION*

Variable	Range of values found in literature
Gravity, °API	22.0 - 30.8
Viscosity, 100°F, SUS	130 - 753 (Average 260)
Viscosity, 210°F, SUS	33 - 61
Flash Point °F	170 - 400 °F
Pour Point	≤ -30
Water, Volume %	1 - 11 %
BS & W, Volume % (Bottom sediments and water)	2.4 - 18 %
Ash, Weight %	1.57 - 3.58 %
Heating Value, BTU/lb.	15,000 - 20,000 BTU/lb.
Sulfur, Weight %	.21 - .48 %
Lead, Weight %	.50 - 1.12 %
Calcium, Weight %	.09 - .17 %
Zinc, Weight %	.08 % (560-1610 ppm)
Phosphorous, Weight %	.05 .09 %
Barium, ppm**	10 - 900 ppm
Iron	95 - 800 ppm
Vanadium	< 5 ppm

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* Waste crankcase oil, untreated

** ppm = parts per million

APPENDIX E

CHARACTERIZATION DATA OF WASTE OILS AND VIRGIN FUELS

Table E-1. **PROPERTIES OF WASTE OIL LUBRICANTS**

Property	Range Values				Composite Range Values
	Ref. 31	Ref. 32	Ref. 33	Ref. 3, 5, 42	
Gravity, °API at 60°F	20.0-24.0	24.6-27.1	24.9	24.6-27.9	20.0-27.9
Specific Gravity	0.910-0.934	0.896-0.905	0.906	0.887-0.904	0.887-0.934
Density, lb/gal	7.58-7.78	7.46	---	7.40-7.54	7.40-7.78
Viscosity, SSU at 100°F	136	234-837	87	148-753	87-837
Viscosity, Centistokes	28.8	50.3-180.6	17.3	31.5-162.6	17.3-180.6
Pour Point, °F	---	< (-40)-(-30)	---	≤ -30	< (-40)-(-30)
Flash Point, °F	---	194-415	---	175-400	175-415
Heating Value, BTU/gal	105,555-129,110	139,250-143,360	---	142,820-143,260	105,555-143,360
Heating Value, BTU/lb	13,571-16,928	18,990-19,300	---	19,000-19,300	13,571-19,300
Neutralization Number, mg KOH/gm	---	---	---	4.0-14.3	4.0-14.3
BS&W, vol %	5.0-22.0	0.3-0.7	0.1	0.6-18.0	0.1-22.0
Sulfur, wt %	0.30-0.59	0.30-0.65	---	0.21-0.52	0.21-0.65
Ash, wt %	0.90	1.30-1.70	1.60	0.03-3.78	0.03-3.78
Silicon, ppm[a]	200-800	875	---	10-400	10-875
Calcium, ppm[a]	800-3,000	1690	1109	700-2,690	700-3,000
Sodium, ppm[a]	80-300	16-19	---	20-110	16-300
Iron, ppm[a]	80-500	562	---	50-2,000	50-2,000
Magnesium, ppm[a]	300-1,000	214	1108	10-500	10-1,108
Lead, ppm[a]	800-6,600	2,180-6,800	6655	960-11,200	800-11,200

Table E-1 (continued). **PROPERTIES OF WASTE OIL LUBRICANTS**

Property	Range Values				Composite Range Values
	Ref. 31	Ref. 32	Ref. 33	Ref. 3, 5, 42	
Vanadium, ppm[a]	3-10	39	---	5	3-39
Copper, ppm[a]	20-100	348	---	5-120	5-348
Barium, ppm[a]	500-2,000	316	---	10-1,000	10-2,000
Zinc, ppm[a]	500-3,000	831	1331	300-1,610	300-3,000
Phosphorus, ppm[a]	500-2,000	831	---	550-1600	500-2,000
Tin, ppm[a]	5-30	112	---	7-30	5-112
Chromium, ppm[a]	8-50	6		10-40	8-50
Nickel, ppm[a]	3-8	4		2-30	3-30
Beryllium, ppm[a]		6			6
Manganese, ppm[a]	5-10	5			5-10
Cadinium, ppm[a]		4			4
Silver, ppm[a]		1			1
Strontium, ppm[a]	10-30				10-30
Aluminum, ppm[a]	100-800			10-50	10-800
Titanium, ppm[a]	5-30				5-30
Boron, ppm[a]	3-10			10-20	3-20
Molybdenum, ppm[a]	2-3				2-3

[a] ppm (as the element) = 0.0001 wt % or 10^4 ppm = 1 wt %

Table E-2a. PROPERTIES OF VIRGIN FUEL OILS - NO. 2 DISTILLATE

Property	Range Values			Composite Range Values
	Ref. 32	Ref. 34	Ref. 35	
Gravity, °API at 60°F	31.8	32.0-35.0	30.2-45.3	30.2-45.3
Specific Gravity	0.868	0.848-0.865	0.800-0.875	0.800-0.875
Density, lb/gal	7.24	7.08-7.22	6.68-7.30	6.68-7.30
Viscosity, SUS at 100°F	34.	34-35	32-40	32-40
Viscosity, Centistokes	2.3	2.4-2.7	1.8-4.1	1.8-4.1
Pour Point, °F	< -40	(-5)-25	(-50)-25	(-50)-25
Flash Point, °F	152	130-180	126-204	126-204
Heating Value, BTU/gal	130,920	137,000	132,900-141,800	130,920-141,800
Heating Value, BTU/lb	18,145	18,975-19,350	19,424-19,895	18,145-19,895
BS&W, vol %	< 0.1		0.0-(< 0.1)	0.0-(< 0.1)
Sulfur, wt %	0.53	0.03-0.36	0.02-0.59	0.02-0.59
Ash, wt %	0.00	0.002-0.005		0.00-0.005

Table E-2b. **PROPERTIES OF VIRGIN FUEL OILS - NO. 4**

Property	Range Values		Composite Range Values
	Ref. 35	Ref. 36	
Gravity, $^{\circ}$API at 60°F	16.2-29.4	15.0-30.0	15.0-30.0
Specific Gravity	0.878-0.958	0.876-0.965	0.876-0.965
Density, lb/gal	7.33-7.99	7.30-8.04	7.30-8.04
Viscosity, SUS at 100°F	35-137	60-300	35-300
Viscosity, Centistokes	2.7-28.7	10.3-64.6	2.7-64.6
Pour Point, $^{\circ}$F	(-25)-75	(-10)-50	(-25)-75
Flash Point, $^{\circ}$F	142-240	---	142-240
Heating Value, BTU/gal	142,200-150,700	141,620-146,971	141,620-150,700
Heating Value, BTU/lb	18,861-19,400	18,280-19,400	18,280-19,400
BS&W, vol %	0.05-0.20	0.00-1.00	0.00-1.00
Sulfur, wt %	0.24-1.23	0.20-2.00	0.20-2.00
Ash, wt %	0.005-0.017	0.00-0.10	0.00-0.10

Table E-2c. PROPERTIES OF VIRGIN FUEL OILS - NO. 6 RESIDUAL

Property	Range Values				Composite Range Values
	Ref. 34	Ref. 35	Ref. 37	Ref. 36,38,41	
Gravity, $^\circ$API at 60°F	12.7-26.0	0.3-22.2	11.7-24.4	7.0-22.0	0.3-26.0
Specific Gravity	0.898-0.981	0.917	0.907-0.988	0.922-1.022	0.898-1.022
Density, lb/gal	7.5-8.2	7.7	7.6-8.2	7.7-8.5	7.5-8.5
Viscosity, SFS at 122°F	50-254	24-350	52		24-350
Viscosity, Centistokes	103-538	48-741	108	7-750	7-750
Pour Point, $^\circ$F		(-10)-95	65	15-90	(-10)-95
Flash Point, $^\circ$F	150-230	150-270	> 200	> 150	150-270
Heating Value, BTU/gal	138,450-151,370	146,800-(> 157,700)	146,100	149,000	146,100-(> 157,700)
Heating Value, BTU/lb	18,460	19,060-(> 20,480)	17,820-19,220	17,410-18,990	17,410-(> 20,480)
BS&W, vol %	0.43-2.00	0.00-0.97		0.05-2.00	0.00-2.00
Sulfur, wt %	1.0-2.8	0.3-4.0	0.9	0.7-3.5	0.3-4.0
Ash, wt %	0.05-0.09	0.00-0.20	0.03	0.01-0.50	0.00-0.50
Silicon, ppm[a]				8.2-164.0	8.2-164.0
Calcium, ppm[a]			6.9-28.7	0.7-95.0	0.7-95.0
Sodium, ppm[a]			9.3-368.0	1-480	1-480
Iron, ppm[a]				10.5-230.0	10.5-230.0
Magnesium, ppm[a]			0.4-1.5	11.5-27.9	0.4-27.9
Lead, ppm[a]			3.0-4.1	1.7	1.7-4.1
Vanadium, ppm[a]	250.0		11.1-182.0	1-380	1-380
Copper, ppm[a]				0.5	0.5

Table E-2c (continued). **PROPERTIES OF VIRGIN FUEL OILS - NO. 6 RESIDUAL**

	Range Values				Composite Range Values
	Ref. 34	Ref. 35	Ref. 37	Ref. 36,38,41	
Chromium, ppm[a]				13.7	13.7
Nickel, ppm[a]				3-118	3-118
Aluminum, ppm[a]				0.5-219	0.5-219
Silver, ppm[a]				0.3	0.3
Titanium, ppm[a]				5.5	5.5
Molybdenum, ppm[a]				2.3	2.3

[a] ppm (as the element) = 0.0001 wt % or 1 wt % = 10^4 ppm

Table E-2d. **PROPERTIES OF VIRGIN FUEL OILS - NO. 6 LOW SULFUR RESIDUAL**

Property	Range Values		Composite Range Values
	Ref. 34	Ref. 38, 39	
Gravity, ^{o}API at 60^{o}F	13.0-27.0	13.2-33.0	13.0-33.0
Specific Gravity	0.892-0.979	0.860-0.978	0.860-0.979
Density, lb/gal	7.4	7.3-8.1	7.3-8.1
Viscosity, SSF at 122^{o}F	36.3-171.0	94.0-1148.6	36.3-1148.6
Viscosity, SSU at 100^{o}F		20-600	20-600
Viscosity, Centistokes	72.5-362.0	< 1.8-198.5	< 1.8-362.0
Pour Point, ^{o}F		5-115	5-115
Flash Point, ^{o}F	200-240	150-370	150-370
Heating Value, BTU/gal		140,000-146,000	140,000-146,000
Heating Value, BTU/lb		18,720-19,700	18,720-19,700
BS&W, vol %		0.01-0.70	0.01-0.70
Sulfur, wt %	< 0.60	0.15-0.36	0.15-0.60
Ash, wt %	0.002-0.10	0.001-0.040	0.001-0.100
Vanadium, ppm[a]		15	15

[a] **ppm (as the element) = 0.0001 wt % or 1 wt % = 10^4 ppm.**

Table E-3a. **PROPERTIES OF VIRGIN COALS - ANTHRACITE**

Property	Range Values			Composite Range Values
	Ref. 36, 40	Ref. 43	Ref. 44[b]	
Fined Carbon, wt %	86-98	67-87		67-98
Volatile Matter, wt %	2-14	3-12		2-14
Moisture	---	1.0-2.3		1.0-2.3
Heating Value, BTU/lb	15,400-17,500	9,620-13,500		9,620-17,500
Sulfur, wt %	---	0.5		0.5
Ash, wt %	---	6.9-28.3		6.9-28.3
Calcium, ppm[a]			252-503	252-503
Magnesium, ppm[a]			425-955	425-955
Lead, ppm[a]			1.8-17.6	1.8-17.6
Vanadium, ppm[a]			17.6-176	17.6-176
Copper, ppm[a]			1.8-123	1.8-123
Phosphorus, ppm[a]			70-1220	70-1220
Tin, ppm[a]			17.6-158	17.6-158
Chromium, ppm[a]			1.8-17.6	1.8-17.6
Manganese, ppm[a]			8.2-10.9	8.2-10.9
Titanium, ppm[a]			1583-2110	1583-2110

[a] ppm (as the element) = 0.0001 wt % or 10^4 ppm = 1 wt %

[b] Reference 44 presents coal components as % (wt) of the total ash without specifying the total ash content of the coal. GCA estimates the total ash content of each coal type by averaging their composite ash content range values. Multiplying average ash content by the composition values obtained from Reference 16 yields elemental compositions as a % (wt) of the coal. These elemental compositions are then converted from % (wt) to ppm.

Table E-3b. PROPERTIES OF VIRGIN COALS - BITUMINOUS

Property	Range Values				Composite Range Values
	Ref.32	Ref. 34	Ref. 36, 40	Ref. 43, 44[b]	
Fined Carbon, wt %			69-86	39-74	39-86
Volatile Matter, wt %			14-36	18-40	14-40
Moisture, wt %	20.6			2.6-12.4	2.6-20.6
Heating Value, BTU/1b	9171.	12,200-13,400	10,500-15,800	11,420-14,550	9,171-15,800
Sulfur, wt %	1.6	2.0-5.0	0.5-4.2	0.6-4.3	0.5-5.0
Ash, wt %	11.2	6.2-18.0	6.6-17.4	3.0-9.1	3.0-18.0
Silicon, ppm[a]			14,800-38,500	9,818-35,343	9,818-38,500
Calcium, ppm[a]			527-11,800	750-15,009	527-15,009
Sodium, ppm[a]			293-645		293-645
Iron, ppm[a]			3,230-24,400	3,672-25,703	3,230-25,703
Magnesium, ppm[a]			435-1,590	190-2,533	190-2,533
Lead, ppm[a]	4.5			20-137	4.5-137
Vanadium, ppm[a]				19-41	19-41
Copper, ppm[a]				23-105	23-105
Barium, ppm[a]				53-462	53-462
Zinc, ppm[a]				45-200	45-200
Phosphorus, ppm[a]				20-40	20-40
Tin, ppm[a]				0.4-550	0.4-550
Chromium, ppm[a]				20-28	20-28
Nickel				13-189	13-189
Beryllium, ppm[a]				0.1-31	0.1-31
Manganese, ppm[a]				13-189	13-189

Table E-3b (continued). PROPERTIES OF VIRGIN COALS - BITUMINOUS

Property	Range Values				Composite Range Values
	Ref. 32	Ref. 34	Ref. 36, 40	Ref. 43, 44[b]	
Silver, ppm[a]				0.5-2.9	0.5-2.9
Strontium, ppm[a]				95-935	95-935
Aluminum, ppm[a]				5,557-19,448	5,557-19,448
Titanium, ppm[a]				315-1,574	315-1,574
Boron, ppm[a]				8.4-101	8.4-101
Molybdenum, ppm[a]				3.2-28	3.2-28

[a] ppm (as the element) = 0.0001 wt % or 10^4 ppm = 1 wt %

[b] Reference 44 presents coal components as % (wt) of the total ash without specifying the total ash content of the coal. GCA estimates the total ash content of each coal type by averaging their composite ash content range values. Multiplying average ash content by the composition values obtained from Reference 16 yields elemental compositions as a % (wt) of the coal. These elemental compositions are then converted from % (wt) to ppm.

Table E-3c. **PROPERTIES OF VIRGIN COALS - SUB-BITUMINOUS**

Property	Range Values			Composite Range Values
	Ref. 36	Ref. 43	Ref. 44[b]	
Fixed Carbon, wt %		38-40		38-40
Volatile Matter, wt %		28-34		28-34
Moisture, wt %		16.5-24.6		16.5-24.6
Heating Value, BTU/lb	8,300-11,500	8,610-9,740		8,300-11,500
Sulfur, wt %	1.0	0.4-2.1		0.4-2.1
Ash, wt %	6.6	3.8-11.2		3.8-11.2
Silicon, ppm[a]	7,390			7,390
Calcium, ppm[a]	12,300			12,300
Sodium, ppm[a]	98			98
Iron, ppm[a]	5,080			5,080
Magnesium, ppm[a]	1,590			1,590
Vanadium, ppm[a]			0.8-44	0.8-44
Copper, ppm[a]			1.5-53	1.5-53
Zinc, ppm[a]			< 525	< 525
Tin, ppm[a]			1.5-7.5	1.5-7.5
Aluminum, ppm[a]			6,935	6,935
Titanium, ppm[a]			188	188

[a] ppm (as the element) = 0.0001 wt % or 10^4 ppm = 1 wt %

[b] Reference 44 presents coal components as % (wt) of the total ash without specifying the total ash content of the coal. GCA estimates the total ash content of each coal type by averaging their composite ash content range values. Multiplying average ash content by the composition values obtained from Reference 16 yields elemental compositions as a % (wt) of the coal. These elemental compositions are then converted from % (wt) to ppm.

Table E-3d. PROPERTIES OF VIRGIN VOALS - LIGNITE

Property	Range Values			Composite Range Values
	Ref.	Ref.	Ref.	
Fixed Carbon, wt %		31		31
Volatile Matter, wt %	35-69	28		28-59
Moisture, wt %		34.8		34.8
Heating Value, BTU/lb	6,300-14,300	7,210		6,300-14,300
Sulfur, wt %	1.0-1.1	0.7		0.7-1.1
Ash, wt %	5.0-12.8	6.2		5.0-12.8
Silicon, ppm[a]	4,180-25,000		8,617	4,180-25,000
Calcium, ppm[a]	16,100-21,300		16,284	16,100-21,300
Sodium, ppm[a]	74-570		1,921	74-1,921
Iron, ppm[a]	2,100-5,910		3,368	2,100-5,910
Magnesium, ppm[a]	603-4,590		5,271	603-5,271
Lead, ppm[a]			8.9-89	8.9-89
Vanadium, ppm[a]			8.9-89	8.9-89
Copper, ppm[a]			8.9-89	8.9-89
Barium, ppm[a]			132-134	132-134
Zinc			8.9-35.8	8.9-35.8
Phosphorus, ppm[a]			50	50
Manganese, ppm[a]			131	131
Aluminum, ppm[a]			4,691	4,691
Titanium, ppm[a]			102-782	102-782
Boron			185	185

[a] ppm (as the element) = 0.0001 wt % or 10^4 ppm = 1 wt %

[b] Reference 44 presents coal components as % (wt) of the total ash without specifying the total ash content of the coal. GCA estimates the total ash content of each coal type by averaging their composite ash content range values. Multiplying average ash content by the composition values obtained from Reference 16 yields elemental compositions as a % (wt) of the coal. These elemental compositions are then converted from % (wt) to ppm.

APPENDIX F

METHOD USED TO GET BLEND PRICES

ASSUMPTIONS

Fuel type	BTU/gal	lb/gal	BTU/lb
Untreated waste oil	139,000	7.5	18,533
Low treated waste oil	145,000	7.3	19,863
High treated waste oil	150,000	7.5	20,000
#2 distillate	137,000	7.2	19,028
#6 residual	152,000	8.0	19,000
Coal	N/A	N/A	13,000

The following gives the amount of fuel (by type) needed to generate 10^6 BTU.

I. Untreated Waste Oil Blends

A. With #2

1. 5-percent blend

6.94 gal of #2
0.40 gal of untreated

2. 50-percent blend

3.61 gal of #2
3.47 gal of untreated

B. With #6

1. 5-percent blend

6.25 gal of residual
0.40 gal of untreated

2. 50-percent blend

3.25 gal of #6
3.47 gal of untreated

C. With coal

1. 5-percent blend

71 lb of coal
0.53 gal of untreated

2. 50-percent blend

32 lb of coal
4.27 gal of waste oil

II. Low treated waste oil blends

A. With #2

1. 5-percent blend

6.8 gal of #2
0.41 gal of low treated

2. 50-percent blend

3.54 gal of #2
3.49 gal of low treated

B. With #6

1. 5-percent blend

6.25 gal of residual
0.41 gal of low treated

2. 50-percent blend

3.31 gal of residual
3.63 gal of low treated

C. With coal

1. 5-percent blend

71 lb of coal
0.58 gal of low treated

2. 50-percent blend

31 lb of coal
4.25 gal of low treated

III. High treated waste oil blends

A. With #2

1. 5-percent blend

6.8 gal of #2
0.40 gal of high treated

2. 50-percent blend

3.54 gal of #2
3.40 gal of high treated

B. With #6

1. 5-percent blend

6.13 gal of #6
0.40 gal of high treated

2. 50-percent blend

3.19 gal of #6
3.40 gal of high treated

C. With coal

1. 5-percent blend

71 lb of coal
0.53 gal of high treated

2. 50-percent blend

30 lb of coal
4.0 gal of high treated

IV. No blending

The following gives the amount of various fuel types that must be combusted to generate 10^6 BTU.

Fuel type	$gal/10^6$ BTU
Untreated waste oil	7.19
Low treated waste oil	6.90
High treated waste oil	6.67
#2 distillate	7.30
#6 residual	6.58
Coal	76.92 $lb/10^6$ BTU

V. Blend prices

(amount of $fuel_1 \times P_1$) + (amount of $fuel_2 \times P_2$) = blend price

Example: 50% blend of high treated and coal

$$(30 \times 0.51) + (4 \times 22.9) = 15.30 + 91.96 = 107.26 \text{ lb}/10^6 \text{ BTU}$$